

Minerva rewarding the Arts

THE

PANORAMA

OF

SCIENCE AND ART;

EMBRACING

THE PRINCIPAL SCIENCES AND ARTS; THE METHODS OF WORKING IN WOOD AND METAL; AND A MISCELLANEOUS SELECTION OF USEFUL AND INTERESTING PROCESSES AND EXPERIMENTS.

BY JAMES SMITH.

IN TWO VOLUMES, WITH ILLUSTRATIVE ENGRAVINGS.

VOL. I.

Thirteenth Edition.

LONDON:—PRINTED AT THE CAXTON PRESS,

BY H. FISHER, SON, & CO.

PUBLISHED AT 38, NEWGATE STREET; AND SOLD BY ALL BOOKSELLERS.

1833.

PREFACE.

AMONG the earliest indications of a mind susceptible of attaining general knowledge, appears that which consists in the delight afforded by mechanical performances. With this disposition, opportunities of acquiring the means of imitative execution, and of perceiving the advantages derivable from the possession of scientific principles, eminently tend to establish that activity of mind, and that predilection for the acquisition of useful knowledge, which beneficially influence the character through life, and present unfailing sources of enjoyment for the hour of solitude and leisure.

If those who are ingenious and skilful in the perception of scientific truth, were practically conversant with the manufacture of every instrument they use, the progression of the sciences would be materially accelerated. The theorist, however excellent and original his views, inevitably suffers many of his plans to perish, when mechanical dexterity is requisite to

verify them, because he cannot contend with the expense or the difficulty of having them executed by others, or has no adequate knowledge of the degree in which they may be realized. The science of chemistry, in the course of a few years, has risen to a pre-eminent station of utility and splendour; and among the leading causes of its advancement, it is observable, that the mechanics who have performed the operations of the laboratory, and contrived and executed the novel part of the apparatus, were the very individuals, who, as men of science, were actuated by expanded views and the zeal of research. Dr. Herschel's observations and discoveries are the most valuable which a single individual has ever made in the departments of astronomy, requiring the aid of instruments; and we find upon investigation, that the telescopes constructed by himself excel all others: even his telescope of forty feet, which is one of the most splendid trophies of mechanical skill existing, was wholly executed under his own direction, by common artisans or labourers.

In adverting to these considerations, the Editor concluded to allot the first portion of these volumes, to the most general and radically important operations in working wood and metal. Architecture and Building follow, after which, to the page which terminates the essay on Gardening, the sciences and their correlative arts are taken up according to the order of succession in which they may be conveniently studied. By this arrangement, Drawing and its dependents are stationed near the conclusion of the

work, which is closed by a selection of Miscellanies, comprising subjects adapted rather for reference than regular perusal.

Historical sketches of the rise and progress of the sciences have been introduced, when they appeared calculated to interest the general reader, to inculcate useful truths, or to facilitate the apprehension of subsequent facts and principles.

Of subjects within the scope of this publication, where minuteness of investigation could not be entered upon, an attempt has been made to delineate the most important features: of those which had yet received no popular illustration, the Editor has been especially solicitous to seek new information; and in aid of this object, he has been favoured by a friend with the communication of an entire essay. He alludes to the treatise on Architecture, which is the production of THOMAS RICKMAN, of Liverpool, whose system of English architecture he cannot doubt will be acceptable to those who are interested in the subject, or who have pleasure in contemplating the monuments of vernacular skill.

The Editor has occasionally availed himself of the language of the ablest writers, where it appeared most conducive to his purpose. Of entire extracts, he has had the pleasure of specifying the source; of those which have been assimilated to his views by alterations, or taken in a detached and limited manner; where the information was of general notoriety, or its

origin uncertain, acknowledgment became superfluous or impracticable.

Convinced that no permanent advantages accrue from attempts to deprecate censure, or to angle for praise, the Editor waves all digression from the general exposition of his plan; but aware that a publication comprising so large a variety of subjects, cannot be free from imperfections, he terminates these prefatory remarks with assuming the liberty to observe, that the communication of hints for emendations will receive his thanks.



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THE

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MECHANICAL EXERCISES

Of Iron.

OF all metallic substances, iron is the most abundantly diffused, and the most intrinsically valuable. It may be detected in plants, and in animal fluids;* it is the chief cause of colour in earths and stones; sands, clays, the waters of rivers, springs, rain, and snow, are seldom perfectly free from it; and in several parts of the world, whole mountains are composed of iron ore. If the use of this metal were lost to mankind, the arts and sciences would dwindle into insignificance, and civilization itself become rapidly retrogressive. An inquiry, therefore, into the properties and means which render it subservient to such important purposes, will not, it is presumed, prove uninteresting to the general reader; while the prudent artisan, whose first care is generally to provide himself with tools adapted to his labours, will attentively review every hint which may improve his knowledge of that material, the proper choice and management of which constitute the first step towards success in mechanical pursuits.

Iron is employed in three states, viz. that of *cast* iron, *wrought* iron, and *steel*. Cast iron is the metal in its first state, rendered fusible by its combination with those two substances which chemists distinguish by the names of carbon and oxygen. In the great iron works, the ore, broken into small pieces, and mixed with a portion of limestone to promote its fusion, is thrown into the furnaces, which are from sixteen to thirty feet high. Baskets of charcoal or coke, in due proportion, are thrown in along with it. A part of the bottom of the furnace is filled with fuel only. This being kindled, the whole is raised by the blast of the

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* Metallic grains of iron have been found in strawberries; and one-twelfth part of the weight of dried oak wood is said to consist of this metal.—The blood contains much iron, to which it owes its red colour.

great bellows, to a most intense heat. The metal, as it is reduced, sinks down through the fuel, and collects at the bottom of the furnace. More ore and fuel are supplied above, and the operation goes on till the melted metal, increasing in quantity, rises almost to the aperture of the blast; a passage is then made for it at the side of the furnace, and it is run into what are called pigs of cast iron. A furnace will furnish daily from two to five tons of iron, according to the richness of the ore, and the skill with which the operation is conducted. Ores of iron combined with magnesia, are very refractory, and, as well as those which contain sulphur and arsenic, require to be roasted before they are cast into the smelting furnace.

Pig iron is of very different qualities; that which is called No. 1, and the fracture of which is of a dark colour, runs so fluid as to be admirably suited for grates, and ornamental work. Cast-iron cutlery is manufactured from it, as no other would run fine enough for the purposes to which it is applied, such as forks and small scissars, fish hooks and needles. These articles obtain by annealing a considerable degree of malleability, and are even rendered capable of being welded. When great strength is required, as for large wheels, beams, pillars, or railways, the iron which contains a smaller proportion of carbon is preferable, as that called No. 2. The proportion of carbon in cast iron varies in the different sorts, from one-fifteenth to one-twenty-fifth. Cast iron also frequently contains a portion of the phosphuret of iron, in which case it breaks of a white colour, and must, from its excessive hardness, be rejected for purposes which require it to be filed, or turned, or cut with the chisel. It may be observed, that the whiter the metal is, the harder it is also; whether these properties are owing to its quality, or the mode of its management. Cast iron expands in passing from the fluid to the solid state; it consequently assumes the exact figure of the mould into which it is poured, a circumstance which adds greatly to its value for casting.

Crude or cast iron is converted into wrought iron, by keeping it in a state of fusion for a considerable time, and repeatedly stirring it in the furnace; the oxygen and carbon which it contains, unite, and fly off in the state of carbonic acid gas, and as this takes place the iron becomes more infusible; it gets thick or stiff in the furnace; and the workmen know, by this appearance, that it is time to submit it to the repeated action of the hammer, or the regular pressure of large steel rollers, by which the parts which still partake of the nature of crude iron so much as to retain the fluid state, are forced out, and the metal is rendered malleable, ductile, more closely com-

pacted, of a fibrous texture, and totally infusible. In this state it is known in commerce by the name of bar iron. The loss of weight sustained by iron, in the process of refining, is considerable, generally amounting to one-fourth, and sometimes to one-half.

Forged, like cast iron, varies greatly in quality. Thus some of it is tough and malleable both when it is hot and when it is cold. This is the iron in common use, and it is the best and most useful. It may be known generally by the equable surface of the forged bar, which is free from transverse fissures, or cracks in the edges; and by a clear, white, small grained, or rather fibrous texture. The best and toughest iron is that which has the most fibrous texture, and is of a clear grayish colour. This fibrous appearance is given by the resistance which its particles make to separation. The texture of the next best iron, which is also malleable in all temperatures, consists of clear whitish small grains, intermixed with fibres. Another kind is tough when it is heated, but brittle when cold. This is called cold-short iron, and is distinguished by a texture consisting of large shining plates, without any fibres. It is less liable to rust than any other description of forged iron. A fourth kind of iron, called red-short, or hot-short, is extremely brittle when hot, and malleable when cold. On the surface and edges of the bars of this kind of iron, transverse cracks or fissures may be seen, and its internal colour is dull and dark.

The quality of iron may be much improved by violent compression, as by forging and rolling, especially when it is not long exposed to violent heat, which injures and at length destroys its metallic properties. But though iron is rendered malleable by hammering, this operation may be continued so long, as to deprive it of its malleability.

Steel is made of the purest malleable iron, by a process called cementation. In this operation, layers of bars of malleable iron, and layers of charcoal, are placed one upon another, in a proper furnace, the air is excluded, the fire raised to a considerable degree of intensity, and kept up for eight or ten days. If upon the trial of a bar, the whole substance is converted into steel, the fire is extinguished, and the whole is left to cool for six or eight days longer. Iron thus prepared is called blistered steel, from the blisters which appear on its surface. In England, charcoal alone is used for this purpose; but Duhamel fouud an advantage in using from one-fourth to one-third of wood ashes, especially when the iron was not of so good a quality as to afford steel possessing tenacity of body as well as hardness. These ashes prevent the steel-

making process from being effected so rapidly as it would otherwise be, and give the steel pliability without diminishing its hardness. The blisters on the surface of the steel, under this management, are smaller and more numerous. He also found that if the bars, when they are put into the furnace, be sprinkled with sea salt, this ingredient contributes to give body to the steel. If the cementation be continued too long, the steel becomes porous, brittle, of a darker fracture, more fusible, and incapable of being welded. On the contrary, steel cemented with earthy infusible powders, is gradually reduced to the state of forged iron again. Excessive or repeated heating in the forge is attended with the same effect.

The properties of iron are remarkably changed by cementation, and it acquires a small addition to its weight, which consists of the carbon it has absorbed from the charcoal, and amounts to about the hundred and fiftieth or two hundredth part. It is much more brittle and fusible than before; though it may still be welded like bar iron, if it has not been fused, or over cemented; but by far the most important alteration in its properties, is, that it can be hardened or softened at pleasure. If it be made red hot, and instantly cooled, it attains a degree of hardness, which is sufficient to cut almost every other substance; but if heated and cooled gradually, it becomes nearly as soft as pure iron, and may with much the same facility be manufactured into any determinate form. A rod of good steel, in its hardest state, possesses so little tenacity that it may be broken almost as easily as a rod of glass of the same dimensions. This brittleness can only be diminished by diminishing its hardness, and in the proper management of this point, for different purposes, consists the art of tempering. The colours which successively appear on the surface of steel slowly heated, are, yellowish white, yellow or straw colour, gold colour, brown, purple, violet, and deep blue. These signs direct the artist in reducing the hardness of steel to any particular standard. If steel be too hard, it will not be proper for tools which are intended to have a fine edge, because it will be so brittle, that the edge will soon become notched; if, on the contrary, it be too soft, it is evident that the edge will turn or bend. Some artists inclose the tools to be hardened, in an iron case or box, and slowly heat them to ignition; they then take the case out of the fire, and drop the pieces into water, in such a manner as will allow them to come as little as possible into contact with the air. This method answers two good purposes; it causes the heat to be more equally applied, and prevents the scaling occasioned by the contact of the air. When the work has been polished, and

well defended from the air, it is, when hardened, nearly as clean as before. If the tool be unpolished, they brighten its surface upon a stone; it is then laid upon burning charcoal, or upon the surface of melted lead, or upon an ignited bar or plate of iron, till it acquires the desired colour; at which instant they plunge it into cold water. The yellowish white indicates a temper so little reduced as to be used for few edge tools; the yellow or straw colour, the gold colour, and the brown, are used for penknives, razors, and gravers; the purple for tools used in working upon metals, especially iron; the violet for springs, and for instruments used in cutting soft substances, such as cork, leather and the like; but if the last blue be waited for, the hardness of the steel will scarcely exceed that of iron. When soft steel is heated to any one of these colours, and then plunged into water, it does not acquire nearly so great a degree of hardness, as if previously made quite hard, and then reduced by tempering. The degree of ignition required to harden steel is different in the different kinds. The best kinds require only a low red heat. It has been ingeniously supposed, that the hardness of steel depends on the intimate combination of its carbon; and, on this supposition, it follows, that the heat which effects this is the best, and that a higher degree will be injurious.

The texture of steel is rendered more uniform by fusion. When it has undergone this operation, it is called cast steel; which is wrought with more difficulty than common steel, because it is more fusible, and is dispersed under the hammer, if heated to a white heat. The cast steel of England is made from the fragments of the crude steel of the manufactories and steel works. A crucible, about ten inches high, and seven inches in diameter, is filled with these fragments, and placed in a wind furnace, like that of the founders, but smaller, because intended to contain one pot only. It is likewise furnished with a cover and chimney, to increase the draught of air. The furnace is entirely filled with coke, and five hours are required for the perfect fusion of the steel. It is then cast into ingots, and afterwards forged in the same manner as other steel, but with less heat and more precaution, as it is more liable to break. Cast steel is about thirty per cent. dearer than other good steel. Its uniformity of texture is for many works an invaluable advantage. It is daily more and more used in this country, but must necessarily be excluded from many works of considerable size, on account of the difficulty of welding it, and the facility with which it is degraded in the fire. Cast steel takes a fine firm edge, and receiving an exquisite polish, of which no other sort of steel is, in so high a

degree, susceptible, it is made use of for all the finest cutlery; but though it may be cast into ingots, it is too imperfectly fluid to be cast into small wares. The tenacity of steel hammered at a low heat, or even when cold, is considerably increased; but the effect of this hammering is taken off by strong ignition. Tools, therefore, made of cast steel, and intended to sustain a good edge, for cutting iron and other metals, are not afterwards softened, but the ignition is carefully regulated at first, as the most useful hardness is produced by that degree of heat which is just sufficient to effect the purpose. Cast steel, annealed to a straw colour, is softened nearly as much as other kinds to a purple or blue.

A convenient mode of tempering a great number of articles at once, and of heating them uniformly, however irregular their shape, is to put them into a proper vessel with as much oil or tallow as will cover them, and then to place them over the fire, or the flame of a lamp, until a sufficient heat is given. Clock and watch pinions, watch verges, &c. are tempered in this manner, sometimes many dozens at once, as expeditiously as a single article. The requisite temper may be known by the following circumstances: when the tallow is first observed to smoke, it indicates the same temper, as that called a straw colour. This will reduce the hardness but little; but if the heat be continued till the smoke becomes more abundant, and of a darker colour, it will be equal to a brown, and indicates a temper that may be wrought, that is, turned or filed, though with difficulty, and only when a mild sort of steel is employed. If the tallow be heated so as to yield a black smoke, and still more abundant, this will denote a purple temper; and if the steel be good, it will now work more pleasantly, though still hard enough to wear well in machinery. The next degree of heat may be known by the tallow taking fire, if a lighted body be presented to it, but yet not so hot as to continue to burn when the light is withdrawn; and this will denote a blue. If the whole of the tallow be allowed to burn away, or burn dry, as termed by the workmen, it imparts the temper which clockmakers mostly use for their work. Further tallow is useless; a small degree of heat more would just be seen in a dark place, or the lowest degree of red heat. Any single article, to spare the trouble of brightening its surface, may be smeared with oil or tallow, and its temper when heated, ascertained in a similar manner. Small articles, such as pendulum and other springs, need not be dropped into water, but only made to pass through the air, by tossing them out, and letting them fall to the ground, which will make them hard enough for most purposes. Small drills may be hardened by holding their points in the flame of a candle, and, when suf-

ficiently hot, suddenly plucking them out; the air will harden them; or they may be laid upon a plate of cold iron or lead, and another plate upon them. They may be tempered, if found too hard, by taking a little of the tallow upon their point, then passing them through the flame at about half an inch above the point, and holding them there till the tallow begins to smoke.

Solid tallow is an excellent material for hardening drills, and other articles, which require considerable hardness, but must not be made brittle; tallow differs from oil, in the absorption or heat for its fusion. Oil is found to harden the surface of steel much more than its internal part, so that it resists the file, but is much less easily broken by the hammer. This effect is owing to its imperfectly conducting quality, and the elevated temperature it demands to be converted into the vaporous state; a covering of coal is also formed round the steel by the burned oil, which greatly retards the transmission of the heat. Any other fluid which covers the steel in like manner, for instance water holding soap in solution, produces a similar effect. Hence the vehicle in which ignited steel is plunged, is of great consequence. The colder it is, the more effectually it hardens the metal. Various artists avail themselves of different substances for this purpose. Some use urine, others water charged with common salt, nitre, or sal ammoniac. Saline liquids produce rather more hardness than common water, and aquafortis, in particular, possesses this property in an eminent degree. Files are covered with the grounds of beer and common salt, and dipped while wet in a powder made of burned or parched horn, leather, or other coaly animal matter. By this means they are not only defended from scaling, by the fused salt, and animal coal, which covers them on all sides, but even rendered rather more steely on the surface, by the absorption of carbon. They are taken out as soon as they have acquired the low red heat called cherry red, and instantly plunged into pure cold water.

When steel is required to possess the greatest possible degree of hardness, it may be quenched in mercury, which will render it so hard as to cut glass like the diamond; but this fluid, it is obvious, can only be used on a small scale.

Wrought iron may be hardened, in a small degree, by ignition and plunging in water, but the effect is confined to the surface; except, as very often happens, the iron contain veins of steel. These are no small impediments to the filing and working of this material.

The general method of choosing steel for edge tools, is to break a bar, observe its fracture, and select the closest grained. But this mode is not always certain, as a variation in the fracture will be occasioned by the difference of its temper, and the

greater or less heat at which it has been hammered; and some steel breaks of a very close grain, though of indifferent quality. The surest method is, to have one end of the bar drawn out under a low heat, such as an obscure red, and then to plunge it suddenly, at this heat, into pure cold water. If it prove hard, for instance, if it will easily cut glass, and requires a great force to break it, whatever its fracture may be, it is good, the excellence of steel being always proportionate to the degree of its tenacity in its hard state. In general, a neat curved line fracture, and even gray texture, denotes good steel, and the appearance of threads, cracks, or brilliant specks, is a proof of the contrary.

If diluted nitrous acid (aquafortis) be applied to the surface of steel previously brightened, it immediately produces a black spot; but if applied to iron in like manner, the metal remains clean. By this test it will be easy to select such pieces of iron or steel as possess the greatest degree of uniformity; as the smallest vein of either upon the surface, will be distinguished by its peculiar sign.

The hardness and polish of steel may be united, in a certain degree, with the firmness and cheapness of malleable iron, by what is called *case-hardening*, an operation much practised, and of considerable use. It is a superficial conversion of iron into steel, and only differs from cementation in being carried on for a shorter time. Some artists pretend to great secrets in the practice of this art, using saltpetre, sal ammoniac, and other fanciful ingredients, to which they attribute their success. But it is now an established fact, that the greatest effect may be produced by a perfectly tight box, and animal carbon alone. The goods intended to be case-hardened, being previously finished with the exception of polishing, are stratified with animal carbon, and the box containing them luted with equal parts of sand and clay. They are then placed in the fire, and kept at a light red heat for half an hour, when the contents of the box are emptied into water. Delicate articles may be preserved, like files, by a saturated solution of common salt, with any vegetable mucilage to give it a pulpy consistence. The carbon here spoken of, is nothing more than any animal matter, such as horns, hoofs, skins, or leather, just sufficiently burnt to admit of being reduced to powder. The box is commonly made of iron, but the use of it, for occasional case-hardening upon a small scale, may be easily dispensed with; as it will answer the same end to envelope the articles with the composition above directed to be used as a lute, drying it gradually, before it is exposed to a red heat, otherwise it will probably crack. It is easy to infer, that the depth of the

steel induced by case-hardening, will vary with the time the operation is continued. In half an hour it will scarcely be the thickness of a sixpence, and therefore will be removed by violent abrasion, though sufficient to answer well for fire irons, &c. in the common usage of which its hardness prevents its being easily scratched, and its polish is preserved by friction with so soft a material as leather.

The *bluing* of steel has a remarkable influence on its elasticity. This operation consists in exposing steel, the surface of which has been brightened, to the regulated heat of a plate of metal, or of a fire or lamp, till the surface has acquired a blue colour. If this blue coal, so commonly considered rather as ornamental than useful, be partially or wholly removed by grinding, or in any other manner, the elasticity is proportionately impaired, and the original excellence of this property can only be restored by bluing the steel again. Saw-makers first harden their plates in the usual way, in which state they are brittle and warped; they then soften them by blazing, which consists in smearing the plate with oil or grease, and heating it till thick vapours are emitted, and burn off with a blaze They then hammer them flat, and afterwards blue them on a hot iron, which renders them stiff and elastic, without altering their flatness.

It may be useful to apprise the inexperienced, that the hardening of steel increases its dimensions; so that such pieces of work as are finished with nicety in their soft state, will not fit their places when hardened. The amount of this expansion cannot be accurately stated, as it varies in different sorts of steel, and even in the same steel, operated upon at different degrees of heat. Rinman found that bars of steel six inches long, six lines wide, and half an inch thick, were lengthened at least one line, after hardening at a whitish red heat, which is about one-seventieth part of the linear dimensions; but, according to the experiments made by others, the expansion is not so considerable. It is also a curious fact, that intense cold has an unfavourable effect upon steel; so that, in severe frosts, workmen often find their tools incapable of receiving the temper they wish.

A slender rod of wrought iron may be expeditiously converted into steel, by plunging it into cast iron in fusion;—a satisfactory proof that cast iron contains the steel-making principle, which, we need not repeat, is carbon. In fact, as it is principally in the superabundance of its carbon that it differs from steel, many attempts (and not wholly without success) have been made to convert it into the latter, without the intermediate operation of rendering it malleable. But the best

steel made pursuant to this idea, is very imperfect. It is, however, not unimportant to observe, that all cast iron so far resembles steel, as to be hardened, in a high degree, by sudden cooling, which imparts to it, at the same time, whiteness of colour, brittleness, and closeness of texture. This property of crude iron may be advantageously employed on many occasions; for instance, in the fabrication of axles and collars for wheels, which are easily turned or filed in their soft state, and may afterwards be hardened, so as to wear admirably well.

The heat applied to cast iron, previously to its being plunged into water to harden, is greater than that to which steel is subjected for the same purpose; it should be little short of a white heat. Cast iron, also, when once hardened, admits not, like steel, of that hardness being reduced, by various gradations, to any specific degree; to soften it materially, it must be submitted, for some time, to complete ignition, and very gradually cooled.

The smaller ramifications of cast iron work, and those portions of metal which have the furthest to run from the git, are often found so extremely hard, that the best file will make no impression upon them, while the remainder of the casting is sufficiently soft and manageable. This effect is owing to the heat carried off by evaporation from the moistened sand of the mould, by which the portions of metal, under the circum stances alluded to, are suddenly cooled. To increase the number of gits, and to use the sand as dry as possible, are the obvious means of preventing this defect; but when it has taken place, annealing is the only remedy.

The chemical properties of iron, and the best methods of preserving it from rust, to which it is so liable, we shall speak of hereafter. The mechanical management of it, which constitutes our present subject, now requires us to proceed with the operations of

Forging and Welding.

In forging, the fire must be regulated by the size of the work; and in heating the iron, the workmen, when the flame begins to break out, beat the coals, round the outside of the fire, close together with the slice, to prevent the heat from escaping. To save fuel, they damp their coals, and throw water on the fire, if it extend beyond its proper limits. To ascertain the state of the work, they draw it partly out of the fire, and thrust it quickly in again, if not hot enough. The heat the iron receives in forging, is judged of by the eye, and is not commonly distinguished into more than these three degrees, viz. the blood or cherry-red heat, the white flame

neat, and the sparkling or welding heat. The cherry-red heat is used when it is only intended to smooth the surface of the iron, or stiffen it in a small degree, operations which are performed by striking evenly with the hand hammer; with light blows, when smoothness of surface only is wanted, and using considerable force, when it is desirable, at the same time, rather to harden the work. When stiffness alone is required, the iron is usually hammered cold, by which means it may be rendered considerably elastic Bell-springs are rarely made of any thing else than sheet iron thus managed.

In changing the form of iron, the white flame heat is used, and, according to the size of the work, it is battered by one, two, or more men, with sledge hammers, the largest size of which, called About Sledges, are slung entirely round, with both hands nearly at the extremity. When the iron is nearly reduced to the proposed form and size, it is finished with the hand hammer, the dexterous use of which will save much trouble in filing.

When the iron is required to be doubled, or two or more pieces consolidated, the sparkling or welding heat is used, by which the metal is brought nearly to a state of fusion, and appears to be covered with a strong glaze or varnish. This varnish is still more abundant in steel. As soon as the two pieces of iron to be united, have attained the welding heat, they are taken out of the fire with the utmost dispatch, the scales or dirt, which would hinder their incorporation, scraped off, placed in contact at the heated part, and hammered until no seam or fissure remain. If they have not been sufficiently incorporated, the heating and hammering ought to be repeated, until the work is perfectly sound. Workmen differ very considerably in the care they bestow in this respect; and when axletrees and other parts of machinery give way, a defective forging is generally very apparent. To make the iron come sooner to a welding heat, stir the fire with the hearth staff, and throw out the clinkers, as well as the cinders upon which the iron may have run, as they will prevent the coals from burning. The fire for welding should be free from sulphur; and the rods may, in part, be prevented from wasting, by taking care to supply them, at the heated part, with powdered glass, or sand; or a mixture of sand and the scales which fly from ignited iron in hammering. Care must also be taken to prevent the iron from running, which will make it so brittle as to prevent its forging, and so hard as to resist the file. If this accident occur, the whole of the iron supposed to be injured by the extreme heat to which it has been exposed, must be cut off and rejected.

When it is required to thicken any part of a bar of iron with

out welding, the operation called upsetting must be resorted to. This consists in giving it the white flame heat at the part to be thickened, and, while one end rests upon the anvil, hammering at the other till the required size is produced.

In forging steel, great care must be taken not to use a higher degree of heat than is absolutely necessary to effect the desired purpose, as well as to use the fewest heats possible. To unite steel to iron completely, without injuring the former, is an operation that demands a nicety of management which workmen are not often very anxious to display. Those, therefore, whose purposes require it to be well performed, will only employ men on whom they can depend. It is not always merely for economy, that steel is welded to iron, but often principally with the view of uniting the opposite qualities of the metal in each state. If the mandrel of a lathe were made of the best steel, sufficiently hard to wear well in the collar, it would be snapped by a sudden check: and an axe, wholly of steel, if soft, would be useless; and if hard, would probably neither bear the shock of a violent blow, nor the twisting to which such tools are subjected. But by uniting a proper quantity of iron with the steel, the inconvenience, and even danger, resulting from such accidents, are avoided. In applying them to each other, regard must be paid to the manner in which the tool will be used. For an axe, the edge of which is formed by grinding both sides, the steel is placed in the middle, between two plates of iron; the blade of a plane, which is ground only on one side, requires the iron also to be only on one side, namely, the back of it; and for that part of a mandrel which works in the collar of a lathe, the steel must encircle the iron.

Damascus was anciently famed for the excellence of the steel goods manufactured there, especially its swords, which are said to possess all the advantages of flexibility, elasticity, and hardness. These united distinctions are supposed to have been effected by blending alternate portions of iron and steel; the latter, by repeatedly drawing out, doubling, and welding the work, being diffused throughout the former, almost as completely as a drop of ink is diffused, by intermixture, with a glass of water. But the best attempt which we are at present aware of having been made in England, to imitate Damascus steel, according to the plan here pointed out, did not perfectly succeed, the mass produced having cracked in tempering. It appears probable, that the desired imitation may be effected with much greater advantage by the use of steel alone, the iron from which it is made being judiciously selected, and afterwards very carefully cemented and forged. It is Swedish iron that is mostly converted into steel; but that kind called *old*

sable) which, we believe, comes from Russia,) possesses, in point of tenacity, according to the experiments of an ingenious philosopher, a very decided superiority over every other kind. It would, doubtless, therefore, be suitable for the purpose; the properties of steel being influenced, as will easily be supposed, by the properties of the iron from which it is manufactured: and, in confirmation of what has been said of the advantages of good forging, we may here take notice of the forge hammer,* invented by George Walby, of London, for which invention, the Society for the Encouragement of Arts, &c. rewarded him with their silver medal and forty guineas. Although it weighs seventy pounds, it may be wrought by one man, with the greatest accuracy and ease, at the rate of thirty blows per minute, and performs the work of two or three men. The inventor states to the Society, that the steel is kept in better temper by this hammer, and fewer heats are required for the same work, than in the common way; that the trowels made with it by him, will bear any pressure of bending, and return by their elasticity to their original shape, and they will even cut a chip from a bar of iron, without hurting their edge; they also are lighter and more handy than common trowels, and serve much longer in use.

The steel which contains the smallest proportion of carbon, as, for example, shear steel, is the most easily welded; but it is by fusion, which entirely destroys its fibrous texture, that it is rendered incapable of being welded to itself, and some maintain that genuine cast steel has never been united even to iron by welding. Yet others have stated, that the means by which this may be accomplished, consist in placing between the iron and the steel another kind of steel, in the form of filings, or a thin plate, the iron being brought to a welding heat, and the cast steel made as hot as can be done with safety. Such, however, are the difficulties of the operation, and so frequently imperfect the work when finished, that other means of effecting the union have been resorted to. One of them, for which a patent has been granted, has been brought into common use, for the blades of joiners' planes, and many other purposes; it consists in uniting the steel to the iron with soft solder or tin. In this process, the cast steel, not being exposed to much heat, loses none of its good properties; but the union is not so substantial as that afforded by welding.

* For the description of this hammer, illustrated by an engraving, see the Transactions of the Society for the Encouragement of Arts, Manufactures, and Commerce, or the Repertory of Arts, vol. 7, second series, 1805.

Of forging Iron, and the Tools used in the working of Metals

Minutely to describe the various tools made use of in forging iron, and in the working of metals generally, would be more likely to tire than to please our readers, to whose information on such points, a volume of the most elaborate description would not add so much as a few moments' inspection of workshops, which may be seen in every village of the kingdom. We shall, therefore, on this, as on other occasions of the kind, confine our remarks to particulars which are, for the most part, either not generally practised, or not often communicated by workmen, or not the most likely to catch the eye of the looker-on.

The best position for the *bellows* is on a level with the fire-place, but they are frequently placed higher, and the blast communicated through a bent tube, for the purpose of gaining room near the floor. The small end of the pipe of the bellows passes through the back of the forge, where it is fixed in a strong iron plate, called a tue iron, or patent back, in order to preserve the bellows from injury, and the back of the forge from requiring frequent repair.

The *anvil* is a substantial mass of iron, to the surface of which a plate of steel is firmly welded, and made sufficiently hard to withstand the file, or the blow of a hammer. It is usually made, for forging iron upon, with one or two projecting arms, and is then called a *beak iron*. These arms are useful in giving the requisite form to various sorts of work: when there is only one, it is preferred of a conical shape; when there are two, one of them is pyramidical. They are affixed lengthways, a little below the surface of the body of the anvil, and rather inclining upwards towards the point. In Birmingham, where attic rooms are frequently converted into workshops, the block upon which the anvil is fixed, is placed upon a stratum of sand, which prevents the vibrations that would otherwise be communicated to the floor, and much of the noise which would incommode the inhabitants of the room below. The contrivance is simple, and susceptible of other applications. Clock-makers use very small anvils or beak irons, which they fix in the vice when in use. The anvils of tin-plate workers are of various sizes, and are often made with concavities and projections upon them, by the help of which they can readily communicate different shapes to their work.

The *large vice* must be firmly fixed to the side of the work-bench; to the edge of which its chaps must be parallel, their upper surface being at the same time exactly horizontal. The best elevation for a vice, is that of the workman's elbow, when

the upper arm is held vertically against the side; and the lower arm, for the sake of trying the height, is held at right angles thereto. In filing, if the vice or the work be above this position, which is seldom heeded, or even thought of, the stroke will not be so powerful as the same exertion would otherwise make it; and, whether higher or lower, it will be found exceedingly difficult to carry the file in a horizontal direction. As the teeth on the inner surface of the chaps would mar fine work, if pressed against it sufficiently hard to keep it steady, they are, as often as the occasion requires, covered with plates of lead, about the eighth of an inch thick. These plates must be large enough to extend about half an inch on each side beyond, and an inch above the chaps, to each of which, when screwed tight, one of them is secured by hammering down the projecting parts.

The *hand vice* is used to hold small articles in the act of filing; it is held in the left hand, and the parts of the iron, while pressed upon the end of the bench, or upon a bit of wood or bone in the large vice, are successively turned to the file, which is held in the right hand. A nick is made in the wood or bone, to keep the work from being carried aside by the file.

Hammers, like anvils, are faced with steel, in a state of considerable hardness. Their handles are almost always made of nearly a uniform thickness in every part, or if they differ from such figure, it is not for any specific purpose. Hence the vibrations of the hammer head are communicated to the hand, to which they occasion very unpleasant sensations, and the workman is tired before he has much exerted his strength. If the handle of the hammer, at a little distance from its upper end, be made considerably smaller, for a short space, than in any other part, the alteration will be found a decisive improvement. Such a hammer will, as it is technically termed, *fall well;* diminishing, at the same time, the workman's fatigue, and convincing him that his blows are solid and effectual. Fig. 1. pl. III. will clearly designate this construction: it represents a hammer for chipping iron; for which purpose, the head need not be more than sixteen ounces in weight, and the handle about twelve inches long. In a hammer of any given shape, calculated to give the hardest blows with the least weight, and, consequently, with the least fatigue, the quantity of iron in the head should be equal on the opposite sides of a line supposed to be drawn perpendicular to the centre of the face. Hammers, therefore, made for the purpose of drawing nails, with claws, which lean backwards from this line, are not calculated to produce the best

effect in striking. Clockmakers, tin-plate workers, and braziers, face their planishing hammers upon a grindstone; they then rub them upon a soft deal board, covered with emery and oil, until the scratches of the stone are removed; they next use a Turkey hone and oil, and finish them with putty, or colcothar and water, upon a smooth board. Watch-makers and silversmiths take still more pains with theirs, selecting them free from every flaw, removing every scratch, and giving them an exquisite lustre with colcothar or putty.

In *riveting* two pieces of metal together, if the head of the rivet is not intended to project, the hole must be widened a little at the top and bottom. One of the heads of a rivet should be made before it is put into its place, in which it is secured, by striking the edge of the other end of the shank (previously filed flat) with light blows, till it is evenly spread all round, when heavier blows may be used, till it is sufficiently firm. When the head of a rivet or screw is on a level with the surface of the work, it is said to be countersunk.

In cutting sheet iron or brass, and even bars of the same metals, *shears* are used. They are frequently made three or four feet long; one handle is screwed fast in the vice, or secured to the bench, and the uppermost only is moveable. The harder, and the greater the thickness of the metal they are designed to cut, the more obtuse the angle by which the edge is formed.

A *chisel* is often used instead of a pair of shears, and though it does not cut with so much rapidity, it is, on many occasions, more convenient, as it can be made of different figures, guided in various directions, and stopped at any given point. Plates of metal to be cut with a chisel, are laid, during the operation, upon a mass of lead, or upon an anvil; if the latter be used, they are not cut quite through, to prevent injuring the chisel, yet they are so nearly divided that the separation can be effected by striking them with the hammer while held on the edge of the anvil, or by wriggling them with the hand or in the vice.

Saws for cutting metals, are made very narrow, (see fig. 2. pl. III:) and stretched by a screw at one end; they are made rather thicker on the edge than at the back; the teeth are small, and are not bent like those for joiners' use. Clock and watch-makers often make their saws of broken watch-springs, the temper of which is suitable for the purpose, and the metal commonly excellent. In sawing malleable iron and steel, oil must be used; crude iron and brass require no oil, but for the latter, a very sharp saw is necessary, and it may also be rather harder than for iron.

Metals are sometimes wrought by *chipping*. This operation not only often produces the intended effect in an expeditious manner, but saves much expense in the files which would otherwise be required. It is most frequently applied to cast iron, the dark rind or outside of which, taken as it comes from the mould, is always harder than the rest, and frequently so very hard, that it would spoil the best file in a few minutes, while, at no greater depth than the twentieth part of an inch, or even less, it is nearly as soft as brass. The chisel will penetrate this hard crust, and afterwards, as may be easily understood, its edge need only be made to act upon the soft part. The chisel, for this description of work, need not be more than seven inches long, but it ought to be made of the best cast steel. Fig. 3. pl. III. represents such a chisel.—No. 1, showing the front, and No. 2, the side of it, to point out the nature of its edge. The hammer to be used with it has been already mentioned. It is held in an angle of about forty-five degrees, and the blows of the hammer are given in quick succession. Some dexterity, certainly, which can only be acquired by practice, is requisite, to preserve a tolerably equable surface, but the art is not of difficult acquirement. A pellicle of iron may, by the chisel, be taken from a surface of a hundred square inches, in four or five hours, and when it has been well done, the file very speedily levels the inequalities which it leaves. When much exactness is required, it is advisable to examine the work before the chipping is commenced, and if improper protuberances or hollows appear in it, the chisel must be struck deeper, or not so deep, at such places, as the circumstance dictates.

Malleable iron, in a state of ignition, is easily perforated with a steel *punch*, which is made of the size and shape of the hole required, except that it must always be tapered more or less towards the lower end, to facilitate drawing it out. It is seldom pointed at the extremity, which is hardened without tempering, as the heat of the iron will soften it sufficiently, and sometimes too much; to check the latter effect, it is plunged into water as often as it is supposed to be considerably heated. The hole may be finished with a file, or by hammering it at a low heat upon a smooth mandrel or pin, or by a well tempered triangular square, or octagonal bar, fixed to a handle, and wrought the same way as a carpenter's auger. A tool of this description is called a *rimer*, and is made to taper a little from the handle to the lower end. In using it the motion must be slow. The triangular and square orm answer well for brass, and the softer metals; but the octagonal one is much more suitable for iron; as the other

would take hold so deeply as to break with the force requisite to turn them round. A sharp-pointed punch will penetrate a piece of cold iron, not exceeding the tenth of an inch in thick ness, sufficiently deep to cause a projection on the under side, when this projection is filed off, if the hole does not appear, a repetition of the punching will immediately produce it; and it may be widened by the octagonal tool above-mentioned. Brass may be managed in the same way, with still more facility: the plate of metal to be pierced, should be laid upon lead; or the under surface, opposite the point of the punch, should be placed over a hole in an anvil.

As punching is not applicable to cast iron, nor to small and deep, or very large holes in any metal, and is, besides, apt to throw the piece out of shape, mechanics have recourse, according to the nature of the work they have in hand, to the different methods of

Boring and Drilling.

The steam engines of the present day are not more indebted for their excellence to modern improvements in their construction, than to the new methods which have been adopted to render them faultless in point of workmanship. In the latter respect, the boring of the cylinder presents one of the most remarkable features of difference from the old plans. The way usually was, at some of the first founderies, to put it upon a carriage, insert the cutter block, set the mill to work, hang a cloth at the open end to keep in the dust, and let it bore away, which it would be doing, on a large cylinder, for three weeks or a month; and if it was tolerably smooth, it was said to be well done. As the cylinder is cast hollow, though the moulder pursues the most correct method his art is capable of, yet it is impossible to be certain that, when the mould has received the metal from the furnace, it shall come out quite straight; and if it come out crooked, it must remain so, for this despicable mode of boring will never remedy that imperfection. It is not like boring a solid piece of metal, as in boring ordnance, &c. All that this old boring can do to a cylinder, is to make it round and smooth, for there is nothing to conduct the boring bit in its progress, but the form given it by the moulder, whose best exertions cannot ensure success: it complies, therefore, with the twistings of its road, and the cylinder is inaccurate. If the metal be harder on one side than another, it produces an additional source of imperfection.

The new method of boring originated with John Wilkinson, iron master, and the cylinders were executed in a man-

ner which has not since admitted of improvement. When the process is conducted by an intelligent workman, if the cylinder should be cast ever so crooked, or ever so thick on one side more than another, he can take out the redundancy from that side, and scarcely touch the other. This will readily be admitted, when it is understood, that the cutting apparatus is conducted along a tool (called by the workmen a *boring bar*) which is itself a masterpiece of workmanship, a perfect cylinder. Hence, whatever is carried along this bar, parallel to its axis, must move in a right line. When, therefore, it has been turned with the utmost care and precision, it is to have two grooves cut opposite each other in this direction. A cast iron socket is then bored and ground upon the bar, so as to fit it in the most exact manner. The external part of this socket is made conical, with four or six studs upon the base of it, to receive the cutter block; and fillets fastened upon the inside of it, and falling into the grooves, while they allow it to slide along the bar, prevent its being carried round, unless the bar be carried round at the same time. To give a progressive motion to the socket and cutter block, while the bar is turning on its own axis, a collar of metal is fitted on the socket, and that collar is connected with two racks, long enough to reach through the cylinder, and communicate with a pair of pinions, which being acted upon by two levers, carrying a sufficient weight to overcome all resistance in the operation, the socket is drawn along the boring bar, and the cutters fastened in it effectually perform their work.

In fitting up the boring apparatus, some diversity of practice prevails. By some, a hole, to admit a single rod, is drilled through the whole length of the bar, and a groove is sunk entirely through one side of it, so as to come into the hole thus drilled. A branch from the internal part of the socket is fitted into the groove, with an eye to receive the end of the rod, to which it is secured by a screw, so that when the rod is drawn along, the socket moves at the same time in the same direction. A weight, with a rope over a pulley, is applied to give the progressive motion to the socket upon the bar. This mode of constructing the bar is the best way for the boring of small cylinders, as there is no incumbrance upon the socket; and if the bar is sufficiently strong, it will move with great steadiness.

Ordnance were formerly cast hollow; they are now always cast solid, and afterwards bored by machinery. The gun to be bored lies with its axis parallel to the horizon, and in that position, moving in a collar fixed at each end, it is turned

round its axis. The borer is laid truly horizontal; in the direction of the axis of the gun, and is incapable of motion in any direction except that of its length; and in this direction it is constantly moved, so as to pierce and cut the gun, by means of rack-work, a lever and weight, applied in the manner represented by fig. 4. pl. III, where it is obvious, that if the weight at the upper end of the lever is sufficient to overcome the resistance, the pinion will turn till the lever rests on the ground; at this moment therefore, or a little before, the workman who attends the machinery, taking it out of the hole on the axis of the pinion, into which it is hooked, inserts it in another higher up, and this he continues to do at the proper interval, till the work is finished. The outside of the gun is smoothed at the same time by men, with instruments fit for the purpose, while it revolves, so that the bore may be exactly in the centre of the metal.

Boring differs from drilling only in being commonly applied to larger works. Drilling may be effected in a lathe with great facility. The drill is screwed, or otherwise fastened, upon the spindle, so that its point shall turn exactly opposite the point of the screw in the right hand puppet. The piece to be drilled is then slightly pierced with a punch, where the drilling is to commence, and also where it is intended to come out. Against the latter puncture, the point of the screw in the right hand puppet is directed, and gradually pressed forward as the drill, on turning the wheel, is found to cut. The motion of the wheel must be slow, especially for iron. The rest, or any temporary support, may be used to keep the work steady, which may then be perforated with expedition and accuracy. A short lever, with a weight at the end of it, may be applied to advance the screw, so as to leave both hands of the workman at liberty for other matters.

Small drills, used by clock-makers and others, are usually made of a single piece of steel wire, upon which, about the middle, a pulley or drill barrel is driven, (see fig. 5. pl. III.) Sometimes, a shank or small mandrel is used, with a square hole, about half an inch deep, at the end of it, into which drill bits of various sizes can be alternately inserted. The disadvantage of this construction is, that the drill bit is seldom held true, which causes it to perform indifferently. It is, therefore, but little used by those workmen who can readily furnish themselves with the other kind as they want them. When these small drills are used, they are held horizontally, and pressed against the work by a breast-piece, which is sometimes made of wood, and sometimes of sheet iron; but, in either case, is rather concave on its inside, to

rest more steadily upon the breast, and in the centre of the outside is fixed a bit of steel, for the blunt end of the drill to work in. The drill is turned by drawing backwards and forwards an elastic bow, the string of which is coiled once round its pulley. The best bows are made of steel, and the strings of catgut; the strength of them must be proportioned to the size of the drill. A piece of stout cane makes no bad substitute for a steel bow.

To make large holes, more force is required than can be given by the bow and string, instead of which a brace, not very unlike that used by joiners, is employed, and the drill itself is fitted as a bit; but instead of the stock which, in the joiner's tool, remains stationary, while the rest is turning, we have here a long tapering spindle, which being nothing more than a continuation of the brace, is necessarily carried round at the same time. The upper end of the spindle works in an iron or steel plate, which is fixed on the under side of a beam, called the drill beam. One end of the beam turns upon a transverse pin between two uprights, pierced with various holes, to fix it at different elevations; the other end, which is pressed down by a weight, passes, when great steadiness is wanted, between two other uprights. The point of the bit being then placed upon the part of the metal to be drilled, the brace is revolved by the hand, and a hole to any required depth may be made. The bit should be well fitted to the brace, though, as very small holes are not made with this apparatus, the disadvantage of its shaking a little is not of so much moment as in the breast drill. The drill is commonly fitted up so that the work to which it is applied can be fixed in the vice. Fig. 6. pl. III. represents the manner of fitting up the hand drill, and fig. 7. one of the bits separately.

The vertical part of the crank, by which the hand revolves the drill, ought to be very smooth, or, what is still better, it may be covered with a loose handle. If this handle be made of iron, it may be bent round and soldered; if of wood, it may be made out of a hollow cylinder, cut in two pieces, between which the vertical part of the crank may be enclosed, and it may then be fastened by glue, or by a hoop at either end, the diameter of the hoop being made large enough to pass over any part of the brace.

Drills ought to be made of the best steel, and the cutting part only should be hard; they are therefore tempered by keeping the lower end out of the fire, but heating the rest considerably, till the point attains the desired colour, when it is instantly cooled in the usual manner. By this means, the cutting part of the bit may be tempered to a straw colour,

while the rest is not higher than blue, so that its liability to break when in use, is greatly diminished. We may observe, in passing, that this mode of tempering from the back of the tool, so as to have the edge only in a state of great hardness is observed as a general principle in the art.

The application of a fly wheel to the upper part of the large hand drill, would be a considerable improvement; not merely on account of its weight, but because its centrifugal force would tend greatly to keep the drill exactly vertical.

In drilling, as in sawing, forged iron and steel require oil, but to brass and cast iron none must be used. For brass, also, the drill bit is made thinner, harder, and the cutting edge formed by a more acute angle than for iron.

Filing.

In the working of metals, there is no operation more common than that of *filing*, and perhaps there is none so little understood. A file is an instrument too familiar to every one to require description. To use it well, generally proves one of the most difficult tasks which the practical mechanic has to encounter, and this difficulty is owing more to the want of a proper plan in setting about the work, than to any other cause. Plane surfaces, for instance, for the plates of air-pumps, and a thousand other purposes, are of indispensable use; but a knowledge of the manner in which they may be readily and completely executed, is confined to very few; and a workman, aware of the exactness required from him, can rarely be found who will undertake to execute them. Grinding is the common and dernier resort of those who wish to produce, on such occasions, the last degree of accuracy; but two surfaces of metal may be ground together for ever without being made plane, unless, by some previous operation, all their *cross-windings* are completely removed In the execution, however, of this previous operation, nearly the whole difficulty of the business lies. In what must it consist? Grinding has a tendency to perpetuate any regular convexity or concavity which either surface may have, and even to produce one or other of these forms on each piece, although both were plain to begin with. The application of turning to the production of plane surfaces, (for which see the section on Turning,) is not an easy undertaking, and requires an expensive apparatus; and often the mere fixing (upon the chuck) the metal to be turned, takes as much time as ought to be required for the completion of the work. We would incite, therefore, the ingenious artist to place confidence in the *file*, with which, we hesitate not to assure him,

that more beautiful and accurate workmanship may be executed, than most of those who are, in other respects, very respectable mechanics, are either apprised of or disposed to consider possible. In this line of exertion, we have witnessed, with admiration, the performances of Thomas Jerome, who now holds a situation in the Royal Mint; which has enabled him to introduce into the coinage, and machinery for coining, several valuable improvements. With the file alone, as his cutting and polishing tool, he has not only produced specimens of workmanship which challenge all competition, and the severest scrutiny, but effected his purpose with a degree of expedition, and consequent economy, of which no other method would admit. The work (the appearance of which, though remarkably fine, was only a secondary consideration,) required the exact parallelism of its several sides, some of which presented a surface of not less than fifty or sixty square inches; and in his hands the file did all this, in such a manner as to set at defiance the elegant art of turning, and to render the dirty and tedious process of grinding wholly unnecessary. How often, in provincial towns especially, have embryo inventions been kept back, for the want of workmen of sufficient skill to execute the proposed contrivance; and how often would inventors themselves carry into effect their designs, if they were not filled with the apprehension that the acquirement of a competent share of manual dexterity was too difficult a task to be attempted! Those who have had the most ample opportunities of observation, will not consider these idle surmises; they cannot but be sensible, that the inventions which become publicly known, are few in comparison with those which spring up in the minds of ingenious men, and perish from such obstacles as have been just stated, often, perhaps, with the hour which gave them birth. What one man has accomplished, let not another despair of accomplishing also. Superior opportunities of experience are often vanquished by superior exertions; and if these remarks on the excellence attainable in an art of the first importance to the practical mechanic, should stimulate one person to the improvement of his skill, they will not be useless.

The practical directions belonging to this subject now claim our attention. Here the general principle, upon the proper application of which success depends, may in the first place be noticed; it is simply this, that if a plane surface, already known to be true, could be made use of so as to shew, with perfect facility and correctness, the errors of another upon which the artist may be employed, as often as he wishes to ascertain the state of his work, a file, or any tool by which all

the projections may be removed without reducing the other parts, will enable him at length to bring the latter surface to an exact correspondence with the former. Such a surface is, therefore, indispensably necessary in the art of flat filing; and we may add to it another implement of almost equal utility, though very little used, namely, a perfectly straight steel ruler, for which we shall adopt the technical term, by calling it a *straight edge*. On the production or procuring of these two things, we shall speak in a future section; at present we shall suppose them to be obtained; then an assortment of files follows of course, as also a vice, or some other method of steadily supporting the metal upon which the file is intended to operate.

Files are differently formed, and of various sizes for different purposes, their sections being either square, oblong, triangular, or segmental; the files of these sections are respectively denominated square, flat, three square, or half round. That sort of file called the *safe-edge*, (on account of its not being cut on one edge,) which is flat on both sides, and of equal or nearly equal breadth in every part, is the best for every purpose to which its form admits of its being applied, and is particularly to be recommended for flat filing.

In chusing files, some degree of attention is requisite, and will save much subsequent trouble; a file, the surface of which is twisted in various directions, (a circumstance which often happens in hardening,) will constantly deceive the workman, as it will produce nothing but false strokes. They must, therefore, be chosen free from such imperfection, but a small degree of regular convexity is not detrimental. The goodness of a file, so far as its shape is concerned, may be readily determined by the eye.

It is perhaps too obvious to require remark, that the scratches made by a file will be proportionate to the size of its teeth; and that the larger these are, the greater will be the effect which an adequate force will produce at one stroke: hence the very evident propriety of commencing the work with the coarsest file intended to be used; and afterwards, in regular gradation, employing finer and finer ones, as it approaches to the finished state.—Files may be obtained, the teeth of which are so extremely fine, that they will leave the surface of metal, especially if it be brass, almost as smooth as an oil-stone. These are, however, seldom necessary; and for most purposes, files of three or four degrees of fineness, are quite sufficient.

As most of the articles of manufacture, to which the file can be applied, are composed of flat surfaces; as he who can file a flat surface well, will find no difficulty in executing whatever the file will enable him to do; we shall detail the progress

of a block of metal taken rough from the foundery, till it is brought to a finished state; and supposing a rectangular figure to be aimed at, its surfaces will then be truly flat, and, according to their situation, either exactly parallel, or exactly at right angles to each other. As somewhat greater difficulties occur in filing iron than brass, and as cast iron is not so easy to manage as the other descriptions of the same metal, we shall suppose it to be a block of cast iron. Merely for the sake of having definite ideas of our subject, as we go along, let us suppose it to be nine inches in length, seven in breadth, and one in thickness. On receiving it, the first step is, to examine the state of the metal, whether it be hard or soft, warped or tolerably straight, perfectly solid, or interspersed with cavities. If it prove very hard, which may be known by trying it with a file, it will be advisable to anneal it; which will greatly facilitate our work; but the outside will still be somewhat harder than the internal part, owing principally to some of the sand of the mould closely adhering to it; this outside, or rind, some workmen remove by chipping, in the manner already spoken of; others, who have the convenience, take it off with a large grindstone turned by machinery; and others, again, use the file immediately, taking the precaution only of using, in the first instance, a file that is already rather worn, as a new one would quickly be spoiled. Chipping is upon the whole the most economical and convenient process, and when, for the removal of imperfections, or any other purpose, it is requisite to reduce the block materially, it is decisively to be preferred. If, after the outside has been removed, there appear any cavities or other imperfections, which are not likely to be removed by the file, and which will unfit the piece for its destination, they may be drilled out, and the holes made by the drill filled with rivets. Small imperfections may be removed by drilling to the depth of about half an inch, and then driving in a plug made of wire, which may be fitted sufficiently tight to bear any degree of hardship, and sufficiently correct to avoid the slightest appearance of a flaw, without the trouble, as in riveting, of making the top of the hole wider than the rest. With a view, however, to complete security, some tap the hole they have drilled, and then *screw* in a pin which exactly fits it; but when this is done, and the screw has a fine thread, in filing the surface level, that part of the thread which is nearest to the surface is apt to break off, to the extent of a semicircle, and thus leave the work imperfect; whereas, when the plug or the rivet is well fitted in, the place cannot afterwards be distinguished from the

other parts of the block, by any other circumstance than the superior brightness of the malleable iron.

As the holes in a piece of cast iron, which are occasioned either by stagnated air, or the falling in of part of the mould, have mostly not only very rough surfaces, but are wider internally than at the outside, they may be filled with melted lead, pewter, or some other soft metal, which they will retain: type-metal will answer extremely well, as, from the antimony it contains, it expands in passing from the fluid to the solid state. This mode is applicable when levelness of surface is the principal object in view, and it is not necessary to regard the uniformity of its appearance, the equal hardness of its several parts, or its being able to bear a strong heat. If we were speaking of a piece of metal, eventually to be subjected to considerable stress, we might here observe, that thus to fill up the hollows it contains, will greatly increase its capability of resistance.

Let us now suppose that the block we have in hand, is completely freed from its hard black scurf, and, as far as may be thought necessary, from every imperfection which the subsequent operations with the file are incapable of removing. We now select the file we intend to use first, and in doing this we pitch upon a *safe-edge* one, about fourteen inches long, an inch and a half broad, and containing about fourteen rows of teeth in each inch of its length. In the act of filing, the file is held by the handle, and pushed forward by the right hand; while the left hand, near the wrist, pressing upon its lower end, gives effect to the stroke, which must be directed as nearly horizontal as possible. By the occasional application of the straight-edge to the surface we are filing, in various directions, but in particular, diagonally, we easily ascertain the state of our work, and remove in succession the elevated parts. The inequalities at length become so small, that it would be tedious to apply the straight-edge to discover them; but being provided with a surface which we know to be true, (and which we shall designate by calling it a table, as it ought always to be larger than the work we are filing, and for general purposes, may with much advantage contain several square feet,) we now make use of it, for the detection of the remaining imperfections, in the following manner: we mix finely washed red chalk or ochre, with olive or any other oil which is not viscid, and we rub this mixture upon it with a piece of cloth, so as to cover the whole of it very thinly and evenly. If the surface we are filing be then turned down upon it, and moved a few times backwards and forwards, it will be every-where equally covered with ochre from the table, provided it be equally level. But as this will never happen at the first trial, those parts

which are highest will alone be reddened, and they must be reduced by the re-application of the file. As soon as the marks left by the ochre have disappeared, and we think we have removed the inequalities they pointed out, we again try the state of our work as before, and continue to repeat the same process till it is finished. When it approaches nearly to a perfect plane, the ochre will redden a great number of places in small spots or strips, and then we not only, agreeably to the remark already made, use a fine file, but hold it rather differently. Instead of pressing it down, as when we began, with the broad part of the hand, we now merely press upon it with two or three of our fingers, by which means we are enabled to observe more distinctly the spot upon which we bear, and to move with more expedition from one part to another.

Before we begin to finish our work with much nicety, we carefully attend to one thing: turning that side of the block we have been filing down upon the table, we strike the back of it, at the corners, centre, and various other parts at pleasure, with a mallet, or the end of the handle of a hammer held perpendicularly. If a dead sound, such as would be heard on striking the table itself in a similar manner, be produced, we feel gratified by the assurance thus afforded, that we have none of those twistings of the surface which are technically termed *cross-windings*, to remove; but if a sharp chinking sound be produced, it is evident that the surfaces of the table and the block do not coincide, for the blow of the hammer has pressed one part of the block lower down than it was before, and raised another part; and to the action of the surfaces upon each other thus occasioned, the ringing sound is attributable. If the corner of the block, to the extent of a square inch, or even much less, be lower than the remainder of the surface, in no greater degree than the common thickness of a sheet of writing paper, this mode of trial will make the imperfection very distinctly perceptible. If, therefore, the block will not stand the test of this examination, we immediately proceed, by the use of the ochre, to detect the extent of the elevated parts; and in moving the block upon the table for this purpose, we are careful to press only on those parts under which we know, by our previous trial with the hammer, they are comprised. Having obtained the marks we desire, we file away, to the best of our judgment, the convexities they indicate, and repeat the experiment and filing, till the block will lie perfectly solid upon the table. This object, so essential to good work, being obtained, and it ought always to be obtained as early as possible in our progress, we shall approach with surer steps, to the successful accomplishment of our task.

Use of the callipers and gauge in filing.

The practitioner, however, will soon discover, that although the test by the hammer answers an important purpose, in proving the existence or non-existence of cross-windings, yet its application extends but little further; the depression of any particular part, before it can point it out, must not only extend to the edge of the block, but must embrace a small portion at least of two sides. Without, therefore, expecting from it what it cannot afford us, we use it merely as a collateral help; the use of the ochre simply is our universal test; but if we wish to know the measure of any particular imperfection, we resort to a good straight-edge, the application of the arris of which, to any part we chuse to try, gives us, with the utmost precision, the information we are seeking. If the surface tried be perfectly true, no light will pass between it and the straight-edge; but if any hollow be present, the breadth and depth of the line of light which appears, betrays its extent.—*Arris* is a common term in the arts, applied to signify the line of concourse or meeting of two surfaces.

Let us now suppose that one surface of the block will bear examining in the different ways above mentioned; it will then coincide with the table so exactly, that when laid upon it, the finest hair could not be drawn out, or even moved, at whatever part between the two planes a portion of it were placed. Notwithstanding this, the surface, though very smooth, has not been nicely polished; the polishing we leave, if not to the last, at least till the opposite side, to which we now proceed, is equally advanced. Here we have an additional object to attend to; we have not only to make the second side as level as the first, but also to make it parallel with it at the same time. The flatness is obtained by a repetition of the means adopted to bring the first surface to that state, and the parallelism of the two sides is a necessary consequence of making the block every-where equally thick. Having, therefore, set a pair of callipers to the thickness intended, or adopted some other equivalent mode of measurement, we frequently examine it with respect to this particular. Callipers, in experienced hands, may be made to answer for this purpose very well, but they are apt to mislead the unwary, as they afford different indications with slight differences in the manner of holding them. In using them, therefore, we always hold the centre of the head in such a manner that a line passing through it, and exactly midway between the points, shall be parallel with the surfaces they inclose. Callipers are often superseded by what is called a gauge, which is nothing more than a piece of sheet iron, steel, or brass, cut in the manner shown by fig. 8. pl. III. so that the distance between the

legs A B, which ought to be exactly parallel with each other, will exactly take in the proposed thickness of the block. It is much easier to file correctly with the assistance of a gauge than a pair of callipers; and as the width of the former always remains the same, we have an additional reason for preferring it, when it is probable we shall often have occasion to measure like dimensions; callipers, even if we wish to keep them to one extent, being easily deranged by a fall or other common accident, and the frequent resetting of them frittering away our time.

Those who wish to avail themselves of the utmost refinement of artificial help, will not be displeased by the mention of another expedient belonging to this subject. Two gauges may be made, one of them of the true width, and the other a very little wider; the block may then be filed down to the latter with rather a coarse file, and afterwards to the former with a fine one. Those who think fit to take this pains, can scarcely fail to succeed to their wish. Another hint deserves a place: we are attentive to make the block fit the gauge tightly; for of the degree of tightness we can correctly judge; but if we make them slack to each other, we can hardly determine the degree of that slackness with even tolerable accuracy.

When we discontinued filing the first side, we have remarked, that we left it unfinished or unpolished. The reason for this requires explanation; labour bestowed in polishing, at the time alluded to, would have been thrown away. The heat produced by the strokes of a large coarse file, expands the surface upon which they act, renders it convex, and the opposite one necessarily concave. These effects remain in part, after the equilibrium of temperature is restored. While we are employed upon the first side, they are overlooked, but when, after having nearly finished the second side, we find upon trial with the ochre, that the other no longer affords the same indications of correctness which it did before, we are convinced of the propriety of having postponed the finishing of it. In a block eight or ten inches long, the error seldom exceeds the five-hundredth part of an inch, and therefore not having begun to polish when it occurs, we can use a file, by which it will quickly be removed.

Having now so far accomplished our purpose as to have rendered the two principal surfaces of our block correctly plane and parallel with each other, we immediately direct our attention to the four which yet remain in the rough state; these, for the sake of distinction, we may call the edges. We begin upon one of the two longest of them, and file it true, in the same manner as we did in the first example, except that

we make use of a square, applied alternately from the two sides already filed, in order to assist us in keeping it exactly at right angles with them. As soon as this edge is true, we make the opposite one parallel with it by a suitable gauge, checking the chance of error by applying the square, which can quickly be run along the whole length of the edge; and ascertaining, as usual, the general flatness of the whole surface, by the use of the ochre and table. As soon as two of the edges have been made true, the remaining two are brought to the same state, by a repetition of exactly the same means.

If we are provided with a rectangular bar of iron, or any hard metal, the sides of which are very smooth, and exactly perpendicular when it is placed upon the table, we may make use of it, in the filing of these edges, as follows: cover one side with the ochre and oil, place upon the table either of the sides at right angles with the one thus coated, opposite which place that edge of the block which is to be tried; press the block and the bar down upon the table and against each other at the same time, moving one of them while they are in contact, backwards and forwards two or three times. By the marks left upon the block, we detect at once all its deficiencies. This mode of trial would also completely succeed in other cases; for example, if we had to file the inside of a frame such as printers use to fasten their types in, to which no other method would be so advantageously applicable.

We pass one of our smoothest files along the arris of the two surfaces upon which we are going to apply the square, in order to take off that extreme sharpness, and those overhanging particles of iron, produced by filing, and which would prevent that instrument from affording a correct indication of the angle examined.

As our block is too broad to be held between the chaps of the vice, we placed it, before we began to file the principal surface, upon a piece of stout board, in breadth about an inch each way larger than itself. Close to the edge of the block, we drove a strong nail here and there into the board, so as to prevent its horizontal motion, but not its being lifted up and taken off perpendicularly. By a square piece of wood, about two inches broad, being firmly screwed to the under side of the board, and fastened in the vice, a steady and convenient support is obtained for our work. But as soon as the filing of the edges was commenced, this board was discarded, and the vice alone, its teeth only being covered with lead, was used to hold the block.

Experienced plane-makers and others, who use files to smooth their wood-work, select those, the teeth of which are not jagged by cross cutting, and we find that upon iron, files of this sort answer better for polishing than any other. We accordingly use them of such a degree of fineness as will effect our purpose, if that can be effected by a file: the last degree of smoothness can only be obtained by grinding. We always take care, when using a fine file, to spread the ochre so thin as hardly to colour the table, otherwise we should presently choke up its teeth, and not finish our work with so much exactness. Ochre is too soft a material to injure a file, and when it does choke up the teeth, it may be removed with a brush.

We have now detailed the means by which a rectangular prism of cast iron, possessing a remarkable degree of correctness of figure, may be produced. On the uses for which such a block may be required, on the application of the general plan to other sorts of work, and on the importance and multiplied advantages of correct filing in general, we presume it is unnecessary for us to enlarge. If there be those who are more attentive to authority than reason, and who inquire by whom a process is used, rather than what is its merit, we assure them that the method of filing here pointed out, is adopted in the far-famed manufactory of Bolton and Watt, at the Soho near Birmingham.

Workmen who have various sorts of metal to work, have an economical mode of management in the use of files, which deserves to be noted. They use all their new files to brass in the first instance; when the original keenness of the teeth has been diminished by this metal, they lay them aside, to be ready for filing cast iron; and when they cease to be sharp enough for cast iron, they use them to malleable iron, for which they will serve tolerably well awhile longer. Let this order be reversed; let a new file be used first to malleable iron, then to cast iron, and lastly to brass, it will hardly do more than half the service; the teeth strike into the malleable iron, and the best portion of them is broken off; the file is then of little value for cast iron; and glides over brass, which requires a keen edge, almost without effect, unless seconded by a great exertion of strength.

The last uses of a file may be to smooth wood or metal revolving in the lathe; some keep them for a short time red hot in the open fire, and then retemper them before they use them in this way; the scale which they cast leaving them somewhat sharper than they were previously: others make such of their old files as have stood well into screw-plates and chisels, on the presumption that they cannot have better steel.

Grinding.

We restrict the signification of this term to the abrading of metals and other substances, by rubbing them against each other. In general, some hard body, such as emery, in a pulverulent state, and mixed with water, oil, &c. is interposed between the pieces ground together; but when one or both of them, as in the example of grit-stone, is composed of particles which will cut, and motion alone separate, the powder, and even the fluid, are often dispensed with. When grinding is only employed to produce a smooth shining surface, it is called *polishing*.

An observation or two has already been thrown out on the subject of grinding; but this method of working metals, requires a little further elucidation. If the artist be not fully aware of the general principle upon which he must proceed, and of what grinding will really enable him to do, he will often incur considerable expense and disappointment.

In grinding two surfaces together, the usual sources of error are, that the cutting powder is unequally spread between them, that they are not every where equally hard, and that some parts receive a greater number of strokes than others.

Suppose we have two similar blocks of iron, and wish to make one of them, at least, perfectly flat, from which state, as far as the eye can judge, let it be granted that they are already not very remote. Let us grind them together with emery. Having done this for some time, they assume a very smooth appearance; but we find, upon examining them, that we have not attained our object—they are not plane. If we have been grinding long enough, we shall generally find, that one of them is pretty regularly concave, and the other correspondently convex; and we may be assured that, without some further device, no variety of rectilinear, circular, or elliptical strokes, will ever bring either of them to the state we desire. But suppose we are provided with a third block of a similar size, and concave in about the same degree as one of the two in question; if we grind these two concave surfaces together, they will mutually correct the defects of each other. Here then we are furnished with the key to success in this art:—to grind one surface perfectly flat, it is indispensably necessary to grind three at the same time. In practice, we do not ascertain the state of each surface by experiment, with the view of bringing similar defects together, (as just stated in order to render the explanation more evident,) but proceed by grinding them interchangeably, often reversing their position, pressing upon every part with

an equal weight, spreading the emery, or whatever may be used as the cutting powder, as evenly as possible, sometimes moving diagonally and sometimes from side to side, with an intermixture of rectilinear, circular, and elliptical strokes. To execute good work in this art, so far at least as plane surfaces are concerned, manual labour can alone be depended upon. Though glass is much more easily ground true than most of the metals, yet the plate glass, which is ground by machinery, is perhaps never so perfect as it might be made by the hand, and sometimes parts of looking-glasses called plane, are demonstrably possessed of the properties of concave or convex mirrors.

Emery is the substance most commonly employed as the cutting powder in the grinding of metals. The artist should be provided with it of various degrees of fineness to be used in succession; and as it is necessary that the finest sort should be entirely free from the admixture of coarse grains, it is advisable, on this account, to keep it at a distance from the other kinds. It is the practice of some, not to polish in the same room, or even in the same clothes, they used for the rougher part of their operations. As soon as the emery thrown upon the work, is found to have little or no effect, being converted into mud, it must be entirely washed away, and the supply renewed. When iron or brass have been ground with emery, it is difficult to file them; the file wears very fast, and produces but a slight effect, till the emery which has entered into the pores of the metal is removed.

Water, having the strong recommendation of cheapness, is the fluid most commonly used in grinding; but with oil, metals are cut more evenly, expeditiously, and fewer scratches are produced. It is therefore most used to finish and polish with.

The softer the three bodies intended to be ground, the greater may be their inequalities at the commencement of this labour, with an equal chance of making them perfect in the end. Silicious substances, such as emery and sand, take such powerful hold upon calcareous fossils, to which class of substances belong almost all the hardest stones in common use, that they may be ground, from rather a rough state, till they become very true. The stone and marble masons care nothing about that high degree of accuracy which is here contended for; but if any one who may be disposed to follow the directions given in the last section for filing, be supplied by one of these artists with three slabs of marble, or some close-grained homogeneous stone, made true in their best manner, he may afterwards, with proper care, finish them, according to the principle here laid down, so as to possess a

table, with which he will probably have little reason to be dissatisfied. This must be understood to be the resort, when it is impossible or inconvenient to procure an iron table, which is always to be preferred, and may in fact be manufactured with ease, especially if no extraordinary size is required, by the help of one of stone, obtained as above recited.

The metals are of a much more unyielding nature than stone; and when they are the subjects of our labour, a different line of policy must be pursued. The grinding of them should always be comparatively a short operation. In the removal of considerable inequalities, the file will often do more in a quarter of an hour, than grinding in a whole day; but when the imperfections extended over a surface become exceedingly numerous and minute, such, in short, as a file or any tool which acts only on a small spot at once, is necessarily disposed to leave, and which scarcely at all effect the general level of the whole, the case is reversed, and the file will not produce so finished an effect in a day, as grinding in a quarter of an hour. If any one of three plates or slabs, which have been ground together, will adhere so closely to either of the other two, as to exclude the atmosphere from the surfaces in contact, and allow both to be lifted up by taking hold of one of them, a strong presumption is afforded that all of them are true.

The common *grindstone*, upon which tools are sharpened, requires no description; yet it may be useful to observe, that it will be much easier to grind plane-irons, chisels, &c. upon it, if the circumference in the direction of the axis be kept a little convex. When these and similar tools are ground, the stone should also turn towards the person holding them, so as to run against their edge. Grindstones are often turned by machinery. When the velocity is very great, they do not cut well, and will also sometimes break, a circumstance which has occasioned the most serious accidents. It was formerly the invariable practice to hang them on an axis passing through a piece of wood which occupied a square hole cut through the centre of them; when this wood became wet, the swelling of it powerfully seconded the tendency of rapid motion to break them. The practice of securing them by a circular plate screwed firmly against each side, was therefore adopted, and is becoming more general. The stones upon which cutlery is ground, are carried at the rate of about six hundred feet per second. At Wickersley, near Sheffield, stones are obtained which heat so little that they admit of being used dry. When clogged, they are cleared with a bar of soft iron. This process of dry grinding is of the most destructive nature to the men employed; the sharp particles of iron constantly flying about, find their

way to the lungs, and ultimately produce incurable complaints.

In the manufacture of cutlery, the use of the stone is followed by that of the *lap* or *glazor*. This is formed of a number of pieces of wood, in such a manner that the edge or face may always present the end-way of the wood, or it would change its figure. Some glazors are covered with strong leather, others with an alloy of lead and tin. After the face of them is turned to the proper form and size, it is covered with rakes or notches, which are filled up with emery and tallow. The glazor is carried at the rate of fifteen hundred feet per second.

The *polisher*, in the same branch of art, is a circular piece of wood, running upon an axis like the stone and glazor. It is covered with buff leather, and its surface is from time to time replenished with colcothar. The polisher is not allowed to move quicker than about seventy or eighty feet per second.

A *brush*, consisting of a circular piece of wood fitted upon an axis, and set upon the face with strong bristles, is used to polish those parts which have been filed, and which the lap and the polisher cannot touch.

Copper-plates are prepared for the engraver, by placing them upon a board forming an inclined plane, and rubbing them with a piece of sharp grit-stone, first in the direction of their length, and then in that of their breadth, with rectilinear strokes, till the marks of the planishing hammer and other defects are taken out. The lower edge of the plate may lie in a trough of water, so that the necessary supply of this fluid will be carried over the plate without stopping to throw it on. The scratches left by the grit-stone are then removed by rubbing in the same way with a piece of pumice stone. Charcoal is next used with water, to remove the scratches left by the pumice stone, and the operation is finished with the same substance and a little oil. If the piece of charcoal, when it is tried, glide over the surface with little or no effect, another piece must be selected. Its fitness for the purpose may be distinguished by its making no scratches, yet, when wet and rubbed upon the copper, seeming rough, and making a low murmuring noise. Clock-makers finish the plates between which the wheels of clocks are enclosed, in a similar manner, except that they do not take so much pains to remove every scratch, but obtain a high gloss by rubbing with colcothar or putty laid upon leather. A piece of old hat makes a good polisher, as does also paper rolled up till it forms a cylinder of sufficient size, when the end, being first cut straight, must be used. If the hat, in the dying of which iron is employed, be immersed a few minutes in sulphu-

ric acid, the iron will pass to the state of red oxide, and it then answers the purpose still better than before.

A species of the clay genus, called tripoli, or rotten stone, is much used to prepare metals, marble, and glass, for receiving, after the use of emery or sand, the highest polish of which they are capable. It is of a yellow colour, tastes like common chalk, and is rough or sandy between the teeth, although no sand can be separated from it; and its particles are in fact so fine and soft, as to leave no perceptible scratches.

Goldsmiths, to give the last polish to their wotk, which they commonly call colouring it, employ what is termed polishing rouge. This powder is said to be a very pure native red oxide of iron. Sometimes it is of a red inclining to purple, and has the appearance of very fine colcothar; but this sort is of inferior quality.

Burnishing is too nearly allied to the above methods of polishing, to require a separate section. The burnisher used by the makers of spurs and bits, &c. is partly iron, partly steel, and partly wood. It consists of an iron bar, with a wooden handle at one end, and a hook at the other, to fasten it to another piece of wood held in the vice, while the operator is at work. In the middle of the bow, withinside, is what is properly called the burnisher, being a triangular piece of steel with a tail, whereby it is riveted to the bow.

The iron ore called red hæmatites, or blood-stone, is much used for burnishing metals, but steel burnishers are more common for this purpose than any other sort. They are much varied in shape according to the fancy of the user, or the work for which they are intended. The form shown at fig. 9. pl. III. or some near resemblance of it, is most frequently adopted. The steel of which a burnisher is made should be in a very hard state, entirely free from flaws, and exquisitely polished.

Annealing.

In a considerable number of instances, bodies which are capable of undergoing ignition, are rendered hard and brittle by sudden cooling. Glass, cast iron, and steel, are the most remarkably affected by this circumstance; the inconveniences arising from which are obviated by cooling them very gradually, and this process is called annealing. Glass vessels are carried into an oven over the great furnace, called the leer, where they are permitted to cool, in a greater or less time, according to their thickness and bulk. Steel is most effectually annealed by making it red hot in a charcoal fire, which must completely cover it, and be allowed to go out of its own accord. Cast iron, which may require to be annealed in too large a

quantity, to render the expense of charcoal very agreeable, may be heated in a turf or cinder fire, which must completely envelope and defend the pieces from the air till they are cold. The fire need not be urged so as to produce more than a red heat; a little beyond this, bars and thin pieces would bend, if destitute of a solid support; and would even be melted without any vehement degree of heat. If it be required to anneal a number of pieces expeditiously, and the fire is not large enough to take more than one or two of them at once; or if it be thought hazardous to leave the fire to itself, from an apprehension that the heat might increase too much, the following scheme may be adopted: heat as many of the pieces at once as may be convenient, and as soon as they are red hot, bury them in dry saw-dust. Cast iron, when annealed, is less liable to warp by a subsequent partial exposure to moderate degrees of heat, than that which has not undergone this operation.

The above methods of annealing render cast iron easy to work, but do not deprive it of its natural character. Cast iron cutlery is therefore stratified with some substance containing oxygen, such as poor iron ores, free from sulphur, and kept in a state little short of fusion for twenty-four hours. It is then found to possess a considerable degree of malleability, and is not unfit for several sorts of nails and edge-tools.

Copper forms a remarkable exception to the general rule of annealing. This metal is actually made softer and more flexible by plunging it when red hot into cold water, than by any other means. Gradual cooling produces a contrary effect.

The Straight-edge and Square.

A steel ruler, made, by filing and grinding, perfectly true, is called, by mechanics, a straight-edge, and is an instrument of great use and value to the workman. A straight-edge is not made to any fixed length, which must be varied according to the work to which it is intended to be applied. Unless very short, its breadth is commonly from one to two inches, and its thickness should in all cases be sufficient to support its own weight. To have this property, it must be thicker than would be generally supposed. If it be made thirty inches long, it should not be less than half an inch thick; and if forty inches long, its thickness should be five-eights of an inch. If made materially thinner of these lengths, it will be found to sink in the middle, when supported at the ends; a fact easily ascertained by trying it with the arris of another straight-edge.

This instrument is not even known by name, to a great number of provincial artists, who might be benefited by its use

It should be made of the best cast steel, and filed, with all possible exactness, agreeably to the directions given on that subject. Three must be made at the same time, and they must be ground with strict attention to the general directions for that operation. If they be true, in whatsoever manner they be laid flat upon each other, no light can pass between them. Straight-edges are commonly bevelled on one side, so as to make one edge considerably thinner than the other, in the same manner as common wooden rulers are generally made.

The use of a straight-edge in filing has already been shown. In turning, it is equally useful, where great accuracy is wanted; for example, in turning a cylinder, or a cone, the application of it will instantly show the irregularities of the figure.

Two rectangular prisms, joined at one of their extremities, so as to form a right angle both internally and externally, constitute the instrument called a square. See pl. III. fig. 10. A good square is not often met with; those pieces of metal sold under that name, by the clock and watch tool makers, are generally worthless things, no two of them corresponding with each other. A square, therefore, fit to serve as a guide in the filing of metals, must be the work of the individual artist by whom it is required; or at least he must finish it,—any common workman will make it true to the fiftieth part of an inch. It should be made of good steel, and as it is not to be tempered, it should be well hammered, so as to be rendered stiff and elastic. Like the straight-edge, also, it should be filed with the greatest accuracy, and ground and polished on every side.

To try whether the square is accurate or not, lay it on a level plate of metal at the least as broad as itself, and twice its length, provided also with a ledge perpendicular to it, and known to be truly flat. Against this ledge, so as to reach to about the middle of it, press the external edge of one limb of the square. Hold it steadily there, and with a graver, or some finely pointed steel instrument, draw a line upon the plate, as close to the external edge of the other limb as possible. Now turn over the square, so that it shall lie on its other side, and press the same edge against the other half of the ledge. While thus pressed against the ledge, bring it up to the line just drawn, and accurately examine if another line can be made exactly coincident with it. If this can be done, the square is true; if it cannot, as soon as any part of the square touches the line, draw another line; an acute angle will be produced, and half the breadth of this angle, at any given distance from the ledge, shows the deviation of the instrument from a right angle, at the same distance from the same point.

Screws.

Screws are cut principally by means of screw-plates, by stocks or dies, and in the lathe. The part left standing between the spiral groove of a screw, is called the *thread.* The pin by which the spirals of a screw nut are formed, is called a *tap.* When it is cylindrical, or of the same diameter in every part, it is called a *plug* tap; and when it forms the portion of a cone or a pyramid, it is aptly enough called a *taper* tap, or, as it is the most frequent form, it is simply denominated a tap. The screw cut by a tap is called an *inside* or *concave* screw; the tap itself, and all such screws as are or can be formed by plates or dies, are, for necessary contradistinction, called *outside* or *convex* screws. The screw-plates on sale at the ironmongers' shops, are, in effect, generally worn out before they are used. In a good tap, the groove is sharp at the bottom, as the thread is at the top, and in proportion as they vary from this configuration they may be considered bad. The longitudinal section of ordinary taps and plates, instead of being bounded by a zigzag line, and the thread appearing like a series of triangles touching each other at the base, is bounded by an undulating line, and the groove, though seldom perhaps so bad as to correspond with the segment of a circle, very often comes no nearer a triangle than a portion of the smaller end of an oval. Hence those who require perfect screws for any piece of mechanism, will perceive the necessity of examining the taps and plates intended to be used in making them.

A screw-plate is a cheap and handy instrument for making screws; but as it cuts at once the whole depth of the groove which it will make, it is apt, from the force necessarily employed in forcing it forward, to twist the pin upon which it operates. This is a serious inconvenience, when the pin has been turned, and is required to be quite straight. The best outside screws are therefore cut with what are called stocks or dies, of which we have given a plan in pl. III. fig. 11. although, like screw-plates, they are almost too well known to require notice, unless it be for the purpose of laying before those who are unaccustomed to such things, such hints as may enable them to prevent their work from being spoiled, by the ignorance or carelessness of those whom they employ for its execution. A square frame, A B, is welded to two handles, C D, and on the inside of the opening, next each handle, is an angular projection to the extent shown by the dotted lines. This projection takes hold in a corresponding groove cut in two pieces of steel, *bb*, the edge of one of which is shown at fig. 12.

These pieces are put in at the part *c*, where there is no angular projection; they are then slipped down to their proper place, and a piece of iron put over them, so as to occupy a great part of the space *c*. Upon this piece of iron is pressed the end of the screw *f*, by which the pieces, *bb*, are brought and kept as near to each other as may be required. They are then tapped, so that one-half of the concave screw formed is upon each of them. Before they are tempered, they are often ground or filed so as to make the aperture, when they meet, less than a circle; by which means they can be used to cut a smaller screw than they were originally tapped with. In using them, the screw *f*, can be turned back, so that the aperture will easily admit the pin intended to be cut; thus is obtained the advantage of making the groove very shallow in the first instance, and of deepening it gradually by turning further in the screw *f*.

The bolt or pin intended to be tapped, either with a screw-plate or stocks, is tapered in a small degree at the extremity, previous to the operation. If a screw-plate be employed, it is then pressed downwards upon it, with a force proportionate to its size, and turned, at the same time, with a progressive and retrogressive motion, always, in advancing, (to effect the necessary revolution,) going over a greater space than in returning. Stocks are used with a similar motion, but they are not pressed downwards except at the commencement, before a thread of one revolution has been formed upon the pin. Screw-plates and stocks are often ruined by being used to iron rough from the forge, and covered with scales, which, from their hard gritty nature, grind away the threads.

As in making outside screws, the pin is tapered at the extremity, that the operation may be more readily commenced; so, in making inside screws, (which, when made for screwing upon bolts, are called *nuts*,) the *taper* tap is, for the same reason, used first, and afterwards the *plug* tap to finish with.

The *tap-wrench* is simply a lever, with a hole in or about the middle of it, to admit the rectangular head of the tap, for the purpose of turning it round, in the same manner as the plate and stocks are turned.

The taps used to cast iron are made square; for brass they are sometimes square, and sometimes triangular. As with these shapes the thread can only be on each arris, they clear their way better; and there is room in the hole for the particles which are rapidly cut from these metals; and to clear away which, if this provision were not made, the tap must very frequently be drawn out; or it will be broken by the force applied to overcome the accumulated obstruction to its progress.

Taper taps for malleable iron are frequently squared; but *plug* taps for the same metal are only channelled, in the direction of their length, in two or three places, so as to take out the thread where the grooves are made.

The method of cutting screws in the lathe, will be found in the section on Turning.

Copper.

We refer to the article of Chemistry, for a minute enumeration of the whole of the known metals; but in this place we shall, with the exception of iron, which has already been noticed rather at length, introduce a general practical view of the properties, applications, and combinations with each other, of those most frequently occurring in common arts and common life. Making this our plan, the first object claiming our attention is copper.

Copper is a very brilliant, sonorous metal, of a fine red colour, possessing a considerable degree of hardness, and elasticity. It is extremely malleable, and may be reduced to leaves so fine, that they may be carried about by the wind. Its tenacity is very great. A wire of one-tenth of an inch in diameter, will support a weight equal to 300*lbs.* avoirdupoise without breaking. It does not melt till the temperature is elevated to about 27° of Wedgwood, or (by estimation) 1450° of Fahrenheit. When rapidly cooled, it exhibits a granulated and porous texture. When the temperature is raised beyond what is necessary for its fusion, it is sublimed in the form of visible fumes. Its greatest malleability is at a low red heat. None of the malleable metals is so difficult to file or turn smooth as copper; but it is cut by the graver, or ground by gritty substances, with great ease.

When miners wish to know whether an ore contains copper, they drop a little nitric acid upon it; after a little time, they dip a feather into the acid, and wipe it over the polished blade of a knife; if there be the smallest quantity of copper in it, this metal will be precipitated upon the knife, to which it will impart its peculiar colour.—Roman vitriol, much used by dyers, and in many of the arts, is a sulphate of copper. A solution of this salt is used for browning fowling-pieces and tea-urns.

In domestic economy, the necessity of keeping copper vessels perfectly clean, cannot be too strongly inculcated; but it is worthy of remark, that fat and oily substances, and vegetable acids, do not attack copper while hot; and therefore copper vessels may be used, for culinary purposes, with perfect safety, if no liquor be ever suffered to grow cold in them. The

mere tinning of copper and brass vessels does not afford complete security, as it is never so perfect as to cover every part.

Compounds formed by the mixture of two or more different metals, are called alloys. The alloys of copper, especially those in which this metal predominates, are more numerous and important in the arts than those of any other metal. Many of them are perfectly well known, and have been immemorially in use. The exact composition, and particularly the mode of preparing several, are kept as secret as possible. By the aid of chemistry, we may detect the precise composition of an alloy; yet we may not always be able, by common methods, to produce a mixture having all the excellencies, which, perhaps, mere accident has taught the possessor of the secret to combine.

Brass is the most important of all the alloys of copper. It is more fusible than copper, less liable to tarnish from exposure to the atmosphere, and its fine yellow colour is more agreeable to the eye. It is much more malleable than copper when cold, but less malleable when hot; at a low red heat, it crumbles under the hammer. Sieves of extreme fineness are woven with brass wire, after the manner of cambric weaving, which could not possibly be made with copper wire. Three parts of copper and one of calamine, or native carbonate of zinc, constitute brass. The calamine is first pounded in a stamping mill, and then washed and sifted, in order to separate the lead with which it is mixed. It is then calcined on a broad, shallow, brick hearth, over an oven heated to redness, and frequently stirred for some hours. In some places, it is calcined in a kind of kiln, filled with alternate layers of calamine and charcoal, and kindled from the bottom, where a sufficient quantity of wood has been deposited for the purpose. When the calamine has been thoroughly calcined, it is ground in a mill, and mixed at the same time with a third or a fourth part of charcoal, and is then ready for the brass furnace Being put into crucibles with the requisite proportion of grain copper, copper clippings, or refuse bits of various kinds, the whole is covered with charcoal, and the crucibles luted up with a mixture of clay or loam and horse dung. The heat employed, is, for a considerable time, not sufficient to melt the copper, which it is at length raised so as to fuse, and the compound metal is then run into ingots.

In general, the extremes of the highest and lowest proportion of zinc are from twelve to twenty-five per cent. of the brass. Even with so much as twenty-five per cent. of zinc, brass is perfectly malleable, if well manufactured, though zinc itself scarcely yields to the hammer at common temperatures.

Pinchbeck.—Tombac.—Prince's metal.—Bronze.—Bell metal.

Good brass, when received from the foundery, is nearly inelastic, but exceedingly flexible, and when polished, the naked eye cannot discover any pores, which are frequently observable in the brass made in the country. The liberal use of the hammer imparts a considerable portion of elasticity to brass, and renders it at the same time less flexible. Clock-makers, watch-makers, and all artists who employ this metal, in forms that admit of the operation, hammer it well before they turn or file it, otherwise their work would wear indifferently, and a trifling cause injure its figure. Brass is not malleable when ignited.

Hammering is found to give a magnetic property to brass, perhaps occasioned by the minute particles of iron separated from the hammer and the anvil during the process, and forced into its surface. This circumstance makes it necessary to employ unhammered brass for compass boxes and similar apparatus.

Five or six parts of copper and one of zinc, form pinchbeck. Tombac has still more copper, and is of a deeper red than pinchbeck. Princes' metal is a similar compound, excepting that it contains more zinc than either of the former.

The alloys of copper with different proportions of tin, are of great importance in the arts. They form compounds which have distinct and appropriate uses. Tin renders copper more fusible, less liable to rust, harder, denser, and more sonorous. Copper and tin separately, are not more remarkable for their ductility, than, when united, the compounds they form are for their brittleness.

Eight to twelve parts of tin, combined with one hundred parts of copper, form bronze, which is of a greyish yellow colour, harder than copper, and the usual composition for statues. The customary proportions for bell-metal are, three parts of copper and one of tin. The greater part of the tin may be separated by melting the alloy, and then throwing a little water upon it. The tin decomposes the water, is oxidiz ed, and thrown upon the surface. The proportion of tin in bell-metal is varied a little at different founderies, and for different sorts of bells. Less tin is used for church bells than clock bells; and in very small bells, a trifling quantity of zinc is used, which renders the composition more sonorous, and it is still further improved in this respect, by the addition of a little silver. A small quantity of antimony is occasionally found in bell-metal. When copper, brass, and tin, are used to form bell-metal, the copper is from seventy to eighty per cent. including the proportion contained in the brass, and the remainder is tin and zinc. When tin is nearly one-third of the

alloy, it is then beautifully white, with a lustre almost like mercury, extremely hard, close-grained, and brittle; but when the proportion of tin is one-half, it possesses these properties in a still more remarkable degree, and is susceptible of so exquisite a polish, as to be admirably adapted for the speculums of telescopes. If more tin be added than amounts to half the weight of the copper, the alloy begins to lose that splendid whiteness for which it is so valuable as a mirror, and becomes of a blue grey. As the quantity of tin is increased, the texture becomes rough-grained, and totally unfit for manufacture.

Of Tin.

Tin is a metal of considerable importance in the arts. It is of a silver white colour, very ductile, malleable, and gives out, while bending, a peculiar crackling noise. Its specific gravity is 7.291; a cubic foot weighs about 516*lbs.* avoirdupois. Its purity is in proportion to its levity. It melts at the 400th degree of Fahrenheit's thermometer, and promotes the fusibility of the metals with which it is mixed. Two parts lead and one of tin form plumber's solder, which melts sooner than either of the metals separately. Eight parts of bismuth, five of lead, and three of tin, form a metal which melts at a heat not exceeding that of boiling water. Tea-spoons are made of this alloy, to surprise those unacquainted with their nature: they have the appearance of common tea-spoons, but are melted in hot tea.

Tin is used to form boilers for dyers, and worms for rectifiers' stills. The common mixture for pewter, is 112 pounds of tin, 15 pounds of lead, and six pounds of brass. But the name of pewter is given to any malleable white alloy, into which tin largely enters, and perhaps no two manufacturers employ the same ingredients in the same proportions. The finest kinds of pewter contain no lead whatever, but consist of tin with a small quantity of antimony, and sometimes a little copper. Pewter may be used for vessels containing wine, and even vinegar, provided the tin constitutes about three-fifths of the alloy.

The consumption of tin, in the operation called tinning, is very considerable. The principal secret in tinning, is to preserve the tin and the surface of the metal to which it is intended to be applied, perfectly clean, and in a pure metallic state. Thin plates or sheets of iron, which when coated with tin are so well known under the name of tin-plates, white iron, or latten, are prepared by scouring them with sand. They are then immersed in water acidulated with sulphuric acid, in which they are kept for twenty-four hours, being occasionally turned during that time, so that they may rust equally in every part.

When taken out, they are again scoured and made perfectly clean. They are then dipped in pure water, and kept there till wanted for tinning. The tin is melted in an iron crucible, narrow, but deeper than the length of the iron plates, which are plunged in downright, so that the tin swims over them. The surface of the tin, to prevent its oxidation, is covered with some oily or resinous matter. Reaumur states, that the Germans cover it with suet, previously prepared by frying and burning, which surprisingly puts the iron in a condition to receive the tin. The melted tin must also have a certain degree of heat; if not hot enough, it will not adhere to the iron; and if it be too hot, the coat will be very thin, and the plates discoloured. Plates intended to have a very thick coat, are first dipped into the crucible when the tin is very hot, and afterwards when it is cooler. For the second dipping, the suet must not be prepared, but used in its common state. The tin not only adheres to the surface of iron plates, but penetrates and intimately combines with them.

Copper is tinned after it has been formed into utensils. If the copper be new, its surface is first scoured with salt and diluted sulphuric acid. Pulverized resin is then strewed over the interior of the vessel, into which, after heating it to a considerable degree, a sufficient quantity of melted tin is poured, and spread upon it by means of a roll of hard twisted flax, which renders the coating uniform. Pure tin is rarely used for this purpose; it is generally, though injuriously, alloyed with a small proportion of lead. The use of the resin is important; for the heat given to the copper is sufficient to oxidize its surface in some degree, and an alteration of this sort, however slight, would prevent the perfect adhesion of the tin. The resin is equally useful, in preventing the partial oxidation of the tin, or in reviving the small particles of oxide which may be formed during the operation.

For tinning old vessels a second time, the surface is first scraped clean and bright with a steel instrument, or scoured with iron scales, then pulverized sal ammoniac is strewed over it, and the melted tin is rubbed on the surface with a solid piece of sal ammoniac.

The process for covering iron vessels with tin, corresponds with that last described; but they ought to be previously cleaned with the muriatic acid, instead of being scraped or scoured. Iron nails which cannot be conveniently tinned in a bath, are easily covered with tin by including them, with a due proportion of tin and sal ammoniac, in a stone bottle, and agitating them while heating and cooling.

The following method of tinning is highly esteemed for its

permanency and beauty; the utensil is cleaned in the usual manner; its inner surface is beaten on a rough anvil, or scratched with a wire-brush, that the tinning may adhere more closely to the copper; and one coat of pure tin is then laid on with sal ammoniac, as above directed for tinning old copper. A second coat, consisting of two parts of tin and three of zinc, must next be uniformly applied with sal ammoniac, in a similar manner: the surface is now to be beaten; scoured with chalk and water; smoothed with a proper hammer; exposed to a moderate heat; and lastly dipped in melted tin. This sort of tinning effectually prevents the utensils from rusting.

Pins are whitened by filling a pan with alternate layers of them and grain tin; a solution of super-tartrate of potass (cream of tartar) is then poured upon them, and they are boiled for four or five hours. The tartaric acid first dissolves the tin, and then gradually deposits it on the surface of the pins, in consequence of its greater affinity for the zinc which enters into the composition of the brass wire.

There are two kinds of tin known in commerce, viz. *block* tin and *grain* tin. Block tin is procured from the common tin ore; grain tin is found in small particles, in what is called stream tin ore. It owes its superiority, not only to the purity of the ore, but to the care with which it is washed and refined

Of Lead.

Lead unites with most of the metals. It has little elasticity, and is the softest of them all. Gold and silver are dissolved by it in a slight red heat, but when the heat is much increased, the lead separates, and rises to the surface of the gold, combined with all heterogeneous matters. This property of lead is made use of in the art of refining the precious metals.

If lead be heated so as to boil and smoke, it soon dissolves pieces of copper thrown into it; the mixture, when cold, is brittle. The union of these two metals is remarkably slight, for upon exposing the mass to a heat no greater than that in which lead melts, the lead almost entirely runs off by itself. This process, which is peculiar to lead with copper, is called eliquation. It has lately been discovered, that a certain proportion of lead may be mixed with the metal formerly used for white metal buttons, without injuring the appearance; thus affording a considerable addition of profit to the manufacturer.

The consumption of lead for water pipes, cisterns, and to cover buildings, is very extensive. Sheet lead is made by suffering the melted metal to run out of a box through a long

horizontal slit, upon a table prepared for the purpose. The table is generally covered with sand, and the box is drawn over it by appropriate ropes and pulleys, leaving the melted lead behind to congeal in the desired form. The requisite uniformity and thinness are given to these sheets, by rolling them between two cylinders of iron acting upon the same principle as the copper-plate printing press.

The alloy of lead and antimony is used for printers' types. Chaptal made a great variety of experiments to ascertain the best proportions of these metals to each other for this use. He always found four parts of lead to one of antimony form the most perfect composition. But if the antimony be pure, one part of it, to seven or eight of lead, form an alloy too brittle to be extended under the hammer, and as hard as the generality of types. To give hardness to the lead, is not the only use of antimony in this composition. It renders the lead more fusible, more fluid when melted, and as it expands in passing to a solid state, it is calculated to produce a sharper impression of the mould, than could be easily obtained by lead alone. Antimony (which in trade is commonly called regulus of antimony, or regulus only,) requires, when alone, much more heat for its fusion than lead, in combining with which metal, as it is little more than half its weight, it rises to the surface, and requires to be well stirred before it will incorporate. Different parts of the same block of type-metal, often possess very different degrees of hardness. Stereotype plates are almost always harder on the face than on the back.

The method of granulating lead in the making of small shot, is curious. In melting the lead, a small quantity of arsenic is added, which disposes it to run into spherical drops. When melted, it is poured into a cylinder, whose circumference is pierced with holes. The lead streaming through the holes, soon divides into drops, which fall into water, where they congeal. They are not all spherical; therefore those that are so, must be separated; which is done by an ingenious contrivance. The whole are sifted on the upper end of a long, smooth, inclined plane, and the grains roll down to the lower end. But the pear-like shape of the bad grains makes them roll down irregularly, and they waddle as it were to a side, while the spherical ones roll straight on, and are afterwards sorted into sizes by sieves. The manufacturers of the patent shot have fixed their furnace, for melting the metal, at the top of a tower one hundred feet high, and obtain a much greater quantity of spherical grains, by letting the lead fall into the water from this height, as the shot is gradually cooled before it reaches the water. The arsenic is generally added in ex-

cess to a small quantity of lead, which is covered and closely luted till the incorporation is complete. The compound is called slag or poisoned metal. Ingots of this slag are then added to soft pig lead, in such proportion as is found upon trial to cause it to drop in a globular form. The smaller the shot, the less the height from which it requires to be dropped. The smallest kind need not fall from an elevation of more than eight or ten feet. If the lead, at the time of casting, be too hot, the shot will be apt to crack; and if it be too cold, it will stop up the holes in the cylinder. Instead of the cylinder, a plate of copper, about the size of a trencher, is used in the making of small quantities, with a hollowness in the middle, about three inches compass, pierced with thirty or forty holes, according to the size of the shot wanted. The part containing the holes may be thin; but the thicker the brim, the better it will retain the heat.

The surface of melted lead, as every one knows, becomes quickly covered with a skin or pellicle, often assuming different lively hues at first, and subsequently increasing in quantity and darkness of colour. This effect, termed by chemists oxidation, as it is occasioned by the action of the oxygen of the atmosphere, the activity of which is greater in proportion to the heat of the lead, wastes the metal so fast, that it becomes an object of importance to those who melt much lead, to check its formation, or to convert it, when formed, by the cheapest process, into the metallic state again. A thick coating of ashes of any kind, will check the formation of the oxide, and may be easily pushed back, when a quantity of lead must be taken out of the crucible or melting pan. Charcoal, which is also a good covering for lead in the pan, will convert dross into metal, when assisted by a sufficient heat; fat, oily, and bituminous substances in general, have a similar effect. Common resin answers exceedingly well; thrown in powder upon melted lead, and stirred about, it immediately converts the oxide into metal, causes the surface to shine like mercury, and if any thing remains, it is only a black dirt, containing little or no lead. But in taking off this dirt, small globules of pure lead, skimmed off at the same time, get mixed with it; by throwing it into water, stirring it thoroughly, and pouring off all that does not immediately sink, these grains may be separated. If part of what has appeared to be dirt, is found to be so heavy as instantly to sink to the bottom of water, it may be suspected to be true dross or oxide, and may be revived by mixing it with charcoal, and exposing it to a considerable heat. It is always, however, more prudent and economical, to use means of

preventing the formation of oxide, than to bestow much time upon its revival.

Lead becomes less fluid every time it is melted, and by much or frequent exposure to a high temperature, a state in which it is said to be rotten, is superinduced. To use new lead, and not to melt it oftener, or expose it to a greater heat than is indispensable, are necessary precautions to preserve this metal in its best state. Plumbers, when they cast it into sheets, strew common salt upon the table, to facilitate its spreading, when they are not using new lead, and are for that, or any other reason, apprehensive that it will not run well.

The observations above recited on the management of lead, apply, with equal propriety, to tin, antimony, zinc, bismuth, &c. and all the alloys of these metals with lead or each other. In fact, as lead is so much cheaper than the other metals just enumerated, the object of saving it from destruction is proportionately of less consequence.

Of Zinc.

Zinc is a very combustible metal, of a bluish, brilliant white colour. It seems to form the link between the brittle and malleable metals. It is a modern discovery, that at a temperature of from 210° to 300° of Fahrenheit, it yields to the hammer, may be drawn into wire, or extended into sheets. After having been thus annealed, it continues soft, flexible, and extensible, and does not return to its partial brittleness; thus admitting of being applied to many uses for which zinc was formerly deemed unfit. Hobson and Sylvester, of Sheffield, have taken out a patent, securing to themselves the benefits accruing from the application of this discovery to the arts.

There can now be no difficulty in forming zinc into sheathing for the bottoms of ships, into vessels of capacity, water-pipes, and utensils for various manufactories. As an internal lining for culinary vessels, instead of tin, it has already been applied with success. It is much harder and cheaper than tin, and may be spread very uniformly.

Zinc, at a very elevated temperature, may be pulverized. It may also, like several other metals, be minutely divided, by pouring it, when in fusion, into water. These are the most convenient means of reducing it into small particles. Files have no considerable action upon it; besides, it wears and chokes them up in a short time. Zinc, in filings or small particles, is used to produce those brilliant stars and spangles which are seen in the best artificial fire-works; but the filings of cast iron produce, at a cheaper rate, an effect scarcely inferior.

Calamine, or lapis calaminaris, used in converting copper into brass, is found both in masses and in a crystallized state, and is generally combined with a large portion of silex. It is a native oxide of zinc, combined with carbonic acid. Zinc is also found in an ore called *blende*, or, as the miners term it, Black Jack. It is a sulphuret of zinc: in Wales it was employed till lately for mending the roads.

Soldering.

To unite two pieces of the same or of different metals, by fusing some metallic substance upon them, is called *soldering.*

It is a general rule, that the solder should be easier of fusion than the metal to be soldered by it. It is, in the next place, desirable, though seldom absolutely necessary, nor always attempted, that the solder and the metal to which it is intended to be applied, should be of the same colour, and of the same degree of hardness and malleability.

Solders are distinguished into two principal classes, viz. the hard and the soft solders. For the hard solders, which are ductile, and admit of being hammered, some of the same sort of metal as that to be soldered, is, in the greater number of instances, alloyed with some other which increases its fusibility. Some of the facts already detailed, respecting the metals, prove that the addition made with this view need not always be itself easier of fusion.

The solder for platina is gold, and the expense of it will, therefore, contribute to hinder the general use of platina vessels, even in chemical experiments.

The hard solder for gold, is composed of gold and silver; gold and copper; or gold, silver, and copper. Goldsmiths usually make four kinds; viz. solder of eight, in which, to seven parts of silver, there is one of brass or copper; solder of six, where only a sixth part is copper; solder of four, and solder of three. But many who may have occasionally to solder gold, cannot encumber themselves with these varieties. For general purposes, therefore, the following composition may be provided: melt two parts of gold, with one of silver and one of copper; stir the mass well to make it uniform, add a little borax in powder, and pour it out immediately. If cast into very thin narrow slips, it will be the more handy for subsequent use. To cleanse gold which has been soldered, heat it almost to ignition, let it cool, and then boil it in urine and sal ammoniac.

The hard solder for silver may be prepared by melting two parts of silver with one of brass. It must not be kept long in fusion, lest the zinc of the brass fly off in fumes. If the silver

to be soldered, be alloyed with much copper, the proportion of brass may be increased: for example, the following composition may be used; four parts of silver and three of brass, rendered easier of fusion by the addition of a sixteenth part of zinc. Silver which has been soldered, may be cleaned by heating it, and letting it cool, as directed for gold, but it must be boiled in alum water.

The hard solder for copper and brass, is a soft fusible sort of granulated brass, well known to artists under the name of spelter. It consists of brass mixed with an eighth, a sixth, or even one-half of zinc. The brazier's use no other kind of hard solder, and it is commonly sold by them. As spelter melts sooner than common brass, it serves for the solder of the latter as well as for copper.

Standard silver makes an excellent solder for brass. It is more fusible than spelter, proportionately easier to manage, and equally as durable. A slight demand for silver solder may, to many, be supplied at an easy rate, in consequence of the number of small silver articles in common use, and which are frequently wearing out; no one need to be at a loss for it, while they can provide themselves with a worn-out silver thimble or toothpick.

Iron may be soldered with copper, brass, gold, or silver. Brass or spelter is most commonly used, and the operation is then called brazing; but a carburet of the same metal, viz. the dark grey or most fusible sort of pig iron, called No. 1. is the most durable solder that can be used. The pig iron loses some of its brittleness, and the malleable metal becomes harder in the proximity of the parts soldered.

The parts upon which hard solder is intended to operate, are touched with finely powdered borax moistened with water. They must also, as in all soldering and tinning operations, be perfectly clean. The borax, quickly running into a kind of glass, promotes the fusion of the solder, and preserves from oxidation the surfaces to which it is applied. The pieces intended to be soldered, are fastened together with iron wire, or secured by some contrivance having the same effect. Spelter being composed of so many grains, is apt to spread when the borax boils up; but just as it becomes fused, the workmen bring it to the place where it is wanted, by a slender iron rod. The flame of a lamp, directed by the blow-pipe against the solder covering the intended joint, which must be laid upon charcoal, is sufficient for small things. For large work, a common culinary fire may be made to effect the desired fusion, though a forge is still more convenient. The fire should not touch the work, nor the ashes be allowed to fall upon it.

The soft solders melt easily, but are partly brittle, and therefore cannot be hammered. The solder for lead is usually composed of two parts lead and one of tin. Its goodness is tried by melting it, and pouring about the size of a crown piece upon a table; little shining stars will arise upon it if it be good. By diminishing the proportion of lead, we form what is called strong solder; we may also increase the proportion, which is advisable when we wish to solder vessels for containing acids; because lead is not so easily corroded or dissolved as tin.

The metal with which tea-chests are lined, familiarly called *tea-lead,* is an alloy principally composed of lead and tin. It is generally sold at so low a rate, that it is bought by manufacturers who require alloys of lead, as a cheap method of obtaining that metal already somewhat enriched. In some of it, the proportion of tin is very small: other parcels contain so much tin that they make excellent solder for lead without any further admixture. No solder can be obtained at so low a price as this. These valuable portions of tea-lead may be distinguished by their brilliancy, having suffered little from oxidation; also, when they principally consist of tin, by that crackling noise while bending, which is peculiar to this metal and some of the alloys into which it largely enters. We may observe, in passing, that tea-lead, when mixed with antimony, generally produces a compound of less firmness when cold, and when melted, of less fluidity, than if pure new lead had been used. It is not improbable, that when manufactured into sheets, it is occasionally spoiled by too much heat.

The solder for tin may consist of four parts pewter, one of tin, and one of bismuth, or two parts of tin and one of lead: the latter is the composition mostly used.

The soldering-iron of the tin-plate workers, is an ingot of copper, flattened at the point, in a pyramidical form; it is screwed or riveted to an iron stem driven into a wooden handle. The copper is seldom more than four or five inches long, and when it is worn away, the same stem and handle are used for another piece. The bar of copper is prepared for use, by filing it bright, and tinning it; when sufficiently hot, it will melt and take up the solder, so as to afford a ready means of applying it to the intended juncture. Powdered resin, and sometimes pitch, is used along with the soft solders, to preserve the metals employed from oxidation.

Tin-foil, applied between the joints of fine brass-work, first wetted with a strong solution of sal ammoniac, and held firmly together while heated, makes an excellent juncture, care being taken to avoid too much heat.

TURNING.

Turning is an art universally admired; the simplicity of the operation, the facility with which precision in performing it is attained, the agreeable exercise it affords to the mind, the beauty and utility of its products, have drawn, for the amusement of a leisure hour, as well as for objects of real importance, men of all ranks into the number of its practisers. It is an art of great antiquity, but when or by whom it was first adopted, we must leave the antiquarian to decide. In this place it claims notice, on account of its contributing so essentially to the perfection of several other arts.

The machine in which turning is performed, is called a Lathe. Lathes differ very considerably in their general form, their size, and the materials of which they are made. They are commonly classed according to the manner in which they receive their motion. Hence we have the *Wheel Lathe*, the *Foot Lathe*, the *Hand Lathe* or *Turning Bench*, and the *Pole Lathe*. For very large work, there are other lathes used, which are wrought by horses, water wheels, or steam engines.

We shall, in the first instance, describe the foot lathe, which may be converted into a wheel lathe, as often as occasion demands; as, for this end, it is only necessary to fix it in such a situation as to admit of the requisite addition of a large wheel, turned by one or more men.

Fig. 1. pl. I. is the perspective view of a foot lathe made entirely of iron, excepting the wheel. The shears or cheeks, which constitute the bed of the lathe, and one of which, BB, is seen in front, are fastened, at one end, by two bolts, *c d*, to the upright O; and at the other end by the bolts *a b*, to the upright Q. These bolts pass entirely through the shears and the uprights, and are each of them screwed at the end, so as to be drawn perfectly tight by a nut at the back. The heads are countersunk, so that they lie level in front, and can occasion no inconvenience. The feet P R are cast in the same piece with their respective uprights O Q. They are fastened to the floor by screws passing through them, and are large enough to afford a solid bearing for the lathe. The shears are parallel, and enclose a space for the puppets, or, as they are sometimes called, the headstocks, to slide in.

On the rim of the great wheel or fly, K, are three annular grooves, gradually narrowing to the bottom, the section of each exhibiting an angular indentation, which form is the most suitable to take effectual hold of the band, and give it more power to turn the mandrel E, the pulley F of which has three corre-

sponding grooves, of different diameters, to give it different velocities. The fly wheel, the grooves of which are also of different diameters, has its least diameter upon the same side as the greater diameter of the pulley. The band is made of strong catgut; in order to make it suit, when applied to all the different grooves of the pulley, the wheel K can be elevated or depressed by means of the screws *p p*, each of which acts upon a sliding piece in the uprights. The axle of the wheel, at one end, works in the sliding piece of the upright Q; but at the other in the end of the screw *f*, which passes through the slider of the upright O, and affords the convenience, not only of making the motion of the wheel steady, but of taking it out, or putting it in, without disturbing the other parts of the machine. The axle of the wheel is of iron, except at each extremity, which is steeled, left very hard, and of a conical figure. At L it is bent so as to form a crank, receiving one hook of the connecting rod M, the other hook of which is attached to the treadle frame N. The hooks of the connecting rod being screwed in, can be lengthened or shortened as the wheel is elevated or depressed. The treadle frame is made of wood; to each end of the back part *q q*, is affixed a conical piece of steel, one of which works in a corresponding hole in the foot P, and the other in R, upon the same plan as the axle of the fly.

The puppets C D are cast in one piece. On the under side they have a projecting part, pointed out by dotted lines near B, exactly filling in breadth the space between the shears, upon which they are drawn down by the screws *m m*, which enter this projecting part, and render them immoveable at pleasure. The puppet G is fastened in a similar manner, by the screw *l*. The spindle or mandrel E, runs in a brass or bell-metal collar in each of the puppets C D. The collar in the puppet C is of a single piece, very carefully drilled; but that in the puppet D is in two pieces, which are fitted so as to slide down an angular groove, and further secured by a plate *r* on the top of it, which plate is fastened by two screws. The part E is called the nose of the spindle, and the screw upon it is intended to receive the chucks. The spindle, where it works in the collars, must be steel, welded round the iron part, and turned cylindrical in the most accurate manner. It is supplied with oil by small holes, one of which is drilled from the top of each puppet through the collars. It is intended to be used occasionally as a traversing mandrel, but when not used for this purpose, it has a groove, for a piece of steel on the puppet C to fall into, so as to prevent its horizontal motion. By slackening The screws *l* & *m*, it is evident that the puppets are at liberty to slide horizontally, and that D and G can be fixed at various

distances from each other. G is the puppet moved to suit the length of different work, which requires the use of the point of the screw H as a centre. An accommodation of a few inches is obtained by screwing H further through or out of the head-stock. When the screw H has been brought to its proper place, it is fastened by turning the screw *s*. To prevent the screw *s* from damaging the thread of H, a small piece of brass intercepts the end of it, and is pressed by it upon the screw.

The rest, I, can be affixed at any necessary distance from the axis of the work, by the bolt *i*, which is drawn tight by the nut *k*, the peculiar shape of which is very convenient in practice, as it admits, in turning it, of the ready application either of the hand or any sort of a lever. As the opening which admits the bolt *i* is not stopped off at one end, the rest can be drawn from the lathe without taking off the nut *k* from the bolt *i*, which, when the rest is withdrawn, immediately falls from between the cheeks. The cross part, *g*, of the rest, having a cylindrical stem, which exactly fits a hole passing perpendicularly through the pillar in the fore part of the rest, admits of being moved entirely round, or of being raised or lowered, and it may be fixed in any situation which can be necessary, by the screw *h*.

The pulley F is commonly made of mahogany, or some hard wood which will stand well. On the face, it is covered with a brass plate, upon which are a number of concentric circles, each divided into a different number of equal parts by small holes.* There is a stop *t*, consisting of a stout cylindrical piece that can be moved round on a screw on the puppet D; to the end of it is affixed a thin piece of steel, so that when turned up, and a short point, near the top of it, inserted in any of the divisions of the pulley, it has sufficient spring to keep it there. This contrivance is used to divide the circumference of any thing turned into equal parts. It may also be applied to the cutting of the teeth of wheels, so as to make the lathe not inferior, for this purpose, to the clockmaker's engine, which is often more costly than a complete lathe. To use it in this way, let the part *g* of the rest be drawn out, and a strong plate of iron, with a stem of the same kind, substituted. Upon this plate, let there be a sliding piece, to be pushed forward by a spring, and containing a small circular cutter, with teeth on its circumference like those of a file. The cutter runs horizontally; on its axis must be a pinion, turned by a wheel, of some considerable diameter, and working in the same sliding piece. This wheel has a small winch, by the turning of which the teeth are cut, the stop *t* being first fixed in one of the holes of the brass

plate, the circle used being determined by the number of teeth wanted, and the cutter brought to the circumference of the wheel in the lathe, upon which it is to operate. When one tooth is cut, the stop is slipped into another hole, and the process repeated till all are completed.

The wheel, and consequently the pulley with which the band connects it, is put in motion by pushing down the treadle; the crank, previously to the first push, being brought nearly to its highest elevation. By the momentum which the wheel has thus acquired, the motion is continued, when, as the treadle and crank rise, the workman can exert no power on the machine. As soon as the crank begins to descend, the treadle receives another impulse from the foot, by the repetition of which, at each revolution of the wheel, the force destroyed by friction, and by the tool in the act of turning, is constantly renewed. The wheel is frequently made of iron; it is not then solid, but the rim, which is of considerable weight, is connected by four or five spokes or arms with a centre-piece, through which there is a square hole, for the axis to pass, and it is fastened by thin wedges. When an iron wheel is used, the arms and centre-piece should be light, that nearly its whole weight may be accumulated in its rim or circumference. The arms, also, should present a thin edge in that direction in which they revolve, to lessen the resistance of the air.

The foot-lathe has not power enough for the turning of very heavy work. It is therefore converted into the wheel lathe by using a large fly wheel, (five, six, or seven feet in diameter, for instance, standing in a separate frame, at the distance of several feet, or even yards, from the pulley, and turned by one or two men, who use both hands at once to the winch. The band, to give it greater power over the pulley, is crossed; that part of it which came from the top of the wheel consequently goes directly to the bottom of the pulley, and the men who turn can face the lathe, to assist them in knowing when it is proper to stop, which is necessary when no contrivance is resorted to for stopping the mandrel, without stopping the great wheel. The following description of an ingenious, though more complex, method, adopted by Maudslay, an eminent turner in London, in applying the power of the large wheel, is given in Gregory's able treatise on mechanics. The large fly wheel which the men turn, works by a strap, on another wheel fixed to the ceiling, directly over it; on the axis of this wheel is a larger one, which turns another small wheel or pulley fixed to the ceiling directly over the mandrel of the lathe; and this last has on its axis a larger one which works the pulley F by a band of catgut. These latter wheels are fixed in a frame of

cast iron, moveable on a joint; and this frame has always a strong tendency to rise up, in consequence of the action of a heavy weight; the rope from which, after passing over a pulley, is fastened to the frame: this weight not only operates to keep the mandrel-band tight, when applied to any of the grooves therein, but always makes the strap between the two wheels on the ceiling fit. As it is necessary that the workman should be able to stop his lathe, without the men stopping who are turning the great wheel, there are two pulleys or rollers, (on the axis of the wheel over the lathe,) for the strap coming from the other wheel on the ceiling; one of these pulleys, called the *dead pulley*, is fixed to the axis, and turns with it, and the other, which slips round it, is called the *live pulley:* these pulleys are put close to each other, so that by slipping the strap upon the *live pulley*, it will not turn the axis; but if it is slipped on the other it will turn with it: this is effected by a horizontal bar, with two upright pins in it, between which the strap passes This bar is moved in such a direction as will throw the strap upon the live pulley, by means of a strong bell spring; and in a contrary direction it is moved by a cord fastened to it, which passes over a pulley, and hangs down within reach of the workman's hand: to this cord is fastened a weight, heavy enough to counteract the bell-spring, and bring the strap up to the dead pulley, to turn the lathe; but when the weight is laid upon a little shelf, prepared for the purpose, it will be stopped by the action of the spring.

It may be considered a difficult and expensive undertaking to make an iron lathe upon the plan represented by fig. 1; but if the cheeks be cast in such a manner, that the transverse section of them, when placed as they are to lie in the lathe, shall be like fig. 2, the projecting parts opposite each other, and on the top, which are all that need be filed flat, will be so narrow that the making of them true will be very materially expedited. In metallic lathes, it must not be concealed, there is an elastic tremor which is disadvantageous; but they admit of and retain so much greater exactness in their workmanship, they are so much more compact and durable than wood, that they merit a decided preference, and the use of them is becoming so general, that they will probably, in a short time, supersede every other kind. In its first cost, if the business be set about in a proper manner, an iron lathe need not be made to exceed the price of a really good wooden one; a small quantity of the cheapest sort of wood will make the patterns for a large lathe; one pattern, for example, it is clear, will serve for both the uprights, and the same may be observed of the cheeks, which are also both alike. When a wooden lathe is intended for nice work, it

ought to be made of mahogany; but whether wood or iron be the material, it is recommendable to make the cheeks of considerable depth.

The stronger and the more correct the workmanship of a lathe, the easier it is to execute work in it, with expedition and truth; but good work may be performed with an indifferent lathe, by taking care to cut so little at a time, that the parts of the engine may never be shaken out of contact.

It is essential to a good lathe, that the centres of the collars of the mandrel, and the centre of the screw in the moveable or right hand puppet head, be in one line, parallel to the bed or shears. If the collars and the mandrel be truly formed, the latter, when the rotation of it is slowly made by the hand, will be equally stiff in every stage of its progress, and the wearing parts, when examined, will have, every-where, the same appearance. When the mandrel is fitted with accuracy, the head of the moveable puppet, which must previously be finished in that part which slides between the shears, may be drilled in the following manner: screw firmly upon the mandrel a piece of steel; turn it true; let the right hand end of it be made conical like the extremities of the axle of the wheel K, fig. 1; from the base of this conical end, to at least the same extent as the thickness of the moveable puppet, at the part to be drilled, let it be turned somewhat smaller than the broadest part of the cone. File the cone, so as to leave two or three edges untouched by the file, but which will cut like those of a drill. Now bring up the moveable puppet, and bore it with this tool;—the axis of the hole produced, will be in the same line as the axis of the mandrel. While the puppet is drilling, the screw which fastens it to the cheeks, should be tight enough to prevent its shaking, but not so tight as to prevent its being impelled forward as the tool cuts.

It is not customary, in foot lathes for general purposes, to make the centre of the collars more than eight or nine inches above the bed. As one means of ensuring perfect steadiness, it is always proper to make them as low as the work intended to be done will admit; but in the lathe above described, an arrangement may be made for the occasional turning of work of extraordinary diameters. That part of the puppets C D which slides between the cheeks, does not extend to the front of D; so that when these puppets are turned round, and D stands where C now is, the nose of the mandrel is even with the outside of the upright Q. Hence the body to be turned will be relieved from the interference of the cheeks or the upright, by the chuck, or whatever else is used to effect the rotation. When this plan is adopted, the method of fixing the rest, and

also the right hand centre, when two centres are wanted, must be left to the judgment of those who may require its assistance, as different workmen will have different conveniences for accomplishing the same end; the possession of a substantial bench will, in this case, relieve one person from embarrassment, while the proximity of a wall will afford stability to the fixtures of another.

The method of stopping the motion of the foot lathe, is extremely simple; a considerable piece of thick canvass or leather, is suspended near the circumference of the fly, on that side next the workman, who presses his knee upon the rim, with the canvass or leather interposed, and the momentum of the wheel is too inconsiderable not to be instantly overcome without difficulty.

Fig. 3, is an elevation of one of the standards and feet of the foot lathe, shewn endways. The ribs *a b* are merely intended to afford additional strength to the standard, which, if made a little stronger than the proportion here represented, will not require their aid. The screw by which the sliding piece (for receiving the extremity of the axle of the fly,) is elevated or depressed, is attached by a collar, in which the upper end easily turns round. That part of the standard itself, in which the screw works, is cast with a hole in the centre, in which a brass nut is afterwards inserted.

Fig. 4, is the mandrel separately. When the mandrel is not used as a traversing one, it has generally, besides the shoulder against which the chucks are screwed, another shoulder which is pressed against the collar of the middle puppet by a screw; for an example of this arrangement see fig. 13. When the mandrel is not provided with a shoulder of this sort, it is, at that part which works in the collar of the middle headstock, of a conical figure, so that pressing it forward with the screw at the back, will at all times produce the effect of making it fit the collar. But when this form is given to the mandrel, the friction in the collar is prodigiously increased by the slightest pressure of the back screw, from its operating like a wedge; and it is difficult to regulate it in such a way, that the mandrel is not so tight as uselessly to destroy any part of the power applied to the machine, or so slack as to be unfit for use. The nose of a mandrel is almost always screwed externally, for the reception of chucks, and is besides often furnished with a square hole for the ready insertion of small arbors, boring tools, &c. An inside screw is much better than a square hole, and, in lathes of the best construction, is also more common.

Of Chucks.

The chucks of a lathe are pieces of wood or metal, screwed or otherwise fastened to the nose of the mandrel, and used to sustain the work in its rotation. Their construction is varied very considerably, to suit different purposes. When made of metal, brass is most commonly selected. The work, as the nature of it renders most convenient, is fastened to a wooden chuck by cement, or by glue, or screwed into it, or gently driven into a cell prepared to receive and hold it fast. To sustain the latter operation, or any other violence, wooden chucks are hooped with brass or iron. As it would be almost impossible to screw a wooden chuck upon the convex nose of a mandrel, and take it off as occasion required during the process, without altering the position, it is found much the best to make the medium of fastening it to the mandrel of brass. This may be done in two ways: one-half of a solid cylinder of brass, somewhat thicker than the nose of the mandrel, may be reduced so as to leave a shoulder, and properly screwed to fit the *concave* screw of the mandrel; the remaining part may then be screwed with a coarse thread, for the reception of the chuck, which is to be tightly screwed upon it; the screw and the chuck may then be removed together from the mandrel, as often as may be necessary, and again screwed on exactly to the same bearing. It is proper to use a little oil upon the thread of the screw which enters the mandrel, lest it be so fast that the position of the wooden chuck may alter in a small degree when it is taken out. The other way of adopting the intervention of metal, in securing a wooden chuck, is still more secure, and generally used for large work: it consists in using a short hollow cylinder of brass, internally screwed with the same thread as the external screw of the mandrel, upon which it can consequently be screwed with facility at any time, and as easily taken off. Upon one end of it is soldered a circular plate of iron or brass, so as to form upon it what is called a flanch, the diameter and strength of which must be proportioned to the magnitude of the chuck, and the weight of the work. When the chuck is six inches in diameter, the diameter of the flanch ought not to be less than two and a half or three inches. Four or five holes are made near the circumference of the flanch, for screws to pass through, in order to fasten the brass to the wood.—A wooden chuck is so liable to warp, from changes of temperature, that even after they have once been made true, it is customary to turn them a little every time they are used.

Besides the chucks above described, there are several other kinds, considerably different in their form; some of the most useful we shall describe. Fig. 5, is a universal chuck. It consists of a short, hollow cylinder, one end of which can be screwed upon the nose of the spindle, and on the circumference, at equal distances from each other, and from the edge of the other end, are inserted four screws. As these screws may be altered to any distance within the cylinder, they can be screwed upon work of any size which the cylinder will admit, so as to hold it while it is turned.

Fig. 6, is one part of another contrivance for holding work of various sizes; it is used in conjunction with the centre, fig. 7, and the chuck fig. 8. Suppose we have a bar of iron to turn into a cylinder; let the chuck fig. 8, be screwed upon the nose of the mandrel, and the centre, fig. 7, into it; then put the bar a little way through the tool, fig. 6, which must be fastened thereon by its screw, so that if it be carried round, the bar must revolve at the same time. Suspend the bar, by punch holes, at one end on the centre fig. 7, and at the other on the point of the screw on the right hand puppet, the arm *a* of the tool fig. 6, being first put into the nick of the chuck fig. 8; the bar may then be revolved upon the two centres, and turned with the greatest facility, in every part except that which is immediately under and on the left hand of the tool fig. 6. It can often be so contrived, that the part thus left unturned may be cut off either in the lathe or afterwards; but if this be inconvenient, nothing more is necessary, when this part is all that remains undone, than to reverse the position of the bar, and fasten the tool fig. 6, upon the finished end; we are then at liberty to complete our work. When there is an inside screw at the end of the mandrel, the centre fig. 7, and the chuck fig. 9, are screwed to fit it; but when there is only a square hole, they must necessarily possess a correspondent form.

The chuck, fig. 9, is most commonly used for revolving long pieces of wood. Its prongs, which are sometimes made to stand in a line, and sometimes at equal distances from each other close to the circumference, are driven into the wood; it is then screwed into the nose of the mandrel, and the other end of the wood being supported, by its centre, on the screw, as in the last instance, it is ready for turning.

Of the Boring and Mandrel Collars.

Fig. 10 is a boring collar: the holes are conical, and their centres are all precisely at the same distance from the axis of the collar. This collar is used to support the end of any long

body which must be turned hollow, and which could not be kept steady by a chuck. It is usually made of iron or brass. In using it, remove the common right hand puppet, and provide another considerably lower. Through this low headstock, drill a hole of the same size as that in the centre of the boring collar. The centre of this hole must be in the same perpendicular line as the centre of the mandrel. The collar is attached to it, so as to face the end of the mandrel, by a screw with a button head, tightened at the back with a nut. When properly fixed, the centre of the hole in the boring collar is exactly opposite the axis of the mandrel, and when the largest hole is used, and is therefore uppermost, it entirely clears the top of the headstock to which it is affixed. The end of the cylinder to be bored, being placed in the hole which fits it, the boring tool is held upon a rest against its centre, and the boring may then be performed, with great accuracy, to any required depth.

Fig. 11, is a boring collar with one aperture, capable of adjustment by turning the screw at the top. As for work of different sizes, it requires to be fixed at different heights; the opening for the screw which fastens it, is not circular, but of sufficient length to admit of the required variation. A cylinder revolving in this boring collar, will always touch one point of each side of the triangular aperture, which is sufficient to produce the requisite steadiness while the boring is executed.

Fig. 12, is the collar of the puppet D. Before it is divided, which is done with a fine saw, the hole for the mandrel is very carefully turned. It is very common to make the collars of lathes with steel; but when formed of an alloy containing thirteen or fourteen parts of copper, to two or three of tin, they have much less friction, and will last a very long time, several years perhaps, in constant use, without requiring to be renewed. To make the mandrel and its collar perfectly fit, they may be ground together a little in their places, with finely powdered Turkey hone: emery must not be used, as it would enter the pores of the metals, which could never be freed from it by cleaning.

The Hand Lathe, or Turning Bench.

The wheel of the hand lathe is so situated, that it can be turned by the left hand, while the right is employed in holding the chisel. It is seldom more than eighteen or twenty inches in diameter, and is placed just behind the pulley of the mandrel, so that the winch, at its greatest distance, is within an easy reach to the workman. But the wheel is not an inseparable part of the hand lathe; in which the rotary motion of the work is sometimes produced by the drill bow.

Fig. 13, is an elevation of a hand lathe of the most approved construction. C C are two metallic pillars, firmly screwed to a board or table at the bottom, and at the top to the triangular bar B B. One of the flat sides of this bar is parallel to the table, consequently an angular edge is uppermost. The puppets D E F have angular openings, which exactly fit the bar; two of them, D F, are exactly alike, and an elevation, frontwise, of one of these, is given in fig. 14. These puppets can be taken off the bar, without unscrewing the pillars C C; there is an aperture on both sides of each of them, a little below the under side of the bar; a plate of iron being placed across each puppet, through these apertures, a screw is then passed perpendicularly through the centre of it from below. By pressing this screw against the bar, the puppet is rendered immoveable. The shoulder of the mandrel is pressed against the collar in the puppet E by the screw *a*, the end of which, like that of the mandrel, is convex, and they therefore touch each other only in a point.

The support, H, for the rest, G, is flat on the top; it is moveable along the bar, and fixed exactly in the same manner as the puppets. The pillar and upper part of the rest, resemble the same parts in the foot lathe; but the plate, I, to the end of which the pillar is fixed, has no aperture through it for the admission of a bolt. The under side of it is, however, grooved in the direction of its length, so that the section of it, the narrow way, resembles fig. 16. Hence it admits the button head of a bolt *c*, fig. 15, which passes down the back part of the support H, at the bottom of which it is tightened by a nut. The plate of the rest, from its peculiar formation, can not only, like the plate of the common rest, be drawn out, in a direction at right angles to the axis of the mandrel, but can be turned round upon its support H, a motion which is occasionally advantageous. It may also be observed, that by slackening only the screw which fastens the support H, the rest may be slidden to another part of the bar, without the liability, as in the usual construction, of altering its position otherwise than in the direction of the length of the bar.

The pin *b*, of the puppet F, has a convex centre at one end, and a concave centre at the other. It is perfectly cylindrical, and fits equally well either end foremost. It is not itself screwed, but is fixed at the place required, by a screw from the top of the puppet. It is not unusual to force forward this pin by a screw, which acts upon it exactly in the same way as the screw *a* that prevents the mandrel from receding. This mode of using an unscrewed pin, in the right hand puppet, is used in lathes of all sizes, particularly in those of the very best de-

scription. It should be so perfect a cylinder, as to be air-tight in its socket, either end foremost. It is, however, not approved by some workmen, who consider a screw to be, upon the whole, more convenient.

All the screws, in the lathe fig. 13, by which the puppets and collars are tightened, it will be noticed, have rings to turn them by. This form is more convenient than the common thumb screw, which has no perforation, as either the hand or any small lever that happens to be within reach, can with equal facility be applied, according to the tightness with which they must be fixed.

When a wheel is used to this lathe, it is placed between two standards fixed to a board six or eight inches broad, which, in the direction of its length, lies at right angles to the bar, and slides in an angular groove at each side, in which it has a range of a few inches, for the purpose of tightening the band. When the drill bow is used to effect the rotation of the work, the mandrel is commonly withdrawn, and a centre pin substituted in the puppet D, similar to that in the puppet F. The method of turning upon two centres, whether the bow or the wheel produce the revolution, admits of great truth and precision.

The vibrations of a mandrel, of a short one especially, are much to be dreaded; and cannot be too carefully guarded against by accuracy of workmanship. In proportion as the length of a mandrel is increased, the consequence of a given quantity of vibration is diminished. It is therefore a general rule to make the mandrel as long as will be convenient. In a foot lathe, its length should never be less than fourteen or fifteen inches.

The turning benches of the clock and watch makers, are almost always constructed with a rectangular bar for the puppets to slide upon; but a bar of this sort is much inferior to a triangular one. These artists, also, have frequently no screw upon the nose of the mandrel, but merely a square hole in the end of it. They have arbors of various sizes, one of the ends of which fits this hole, and the other extremity runs upon a centre. These arbors are turned true, but not polished, and they are slightly conical in their figure. To turn wheels and other work which is perforated through the axis, it is only necessary to drive them, with a few light blows, upon these arbors, which, though driven into a cylindrical hole, become sufficiently tight upon them for the operation.

For small lathes, which are exposed to no very extraordinary strain, the mandrel may be made of cast steel, which wears longer and more uniformly than any other kind of steel.

The Pole Lathe.

This lathe is commonly remarkable for the extreme simplicity of its construction; but the manner in which the body to be turned in it receives motion, forms its essential characteristic. It can be easily made by any common artist, at a small expense; it can be wrought by one man, and possesses considerable power; but notwithstanding these important recommendations, it is gradually sinking into disrepute and disuse. As in turning, the tool can only be applied to cut, while the body upon which it is intended to operate revolves in one direction, the pole lathe, which produces a regular alternation of contrary revolutions, wastes the time of the workman. This sort of motion, which forms the principal disadvantage inseparable from the nature of the machine, when used to enforce the action of edge-tools, is a very useful one in some kinds of grinding and polishing. Stop-cocks and valves may more quickly and effectually be made water and air-tight in a pole lathe than in any other kind of a lathe. This hint may be of considerable use to experimentalists, who may require the temporary use of a lathe motion, for purposes of this kind, when they may not have an opportunity of procuring it without more trouble and expense than is convenient. Let a short cylindrical pin be driven into a wall, or fixed piece of upright timber, such as the cheek of a door; place upon it a pulley which is thick enough to hang a little over the end of it. The pole, the treadle, and a temporary rest, are easily arranged. Let the pulley be used as a chuck; they may then give their work the best motion that can be contrived for it. It is not even necessary that the pulley they use should be turned. Three circular pieces of thin board, one of them about an inch in diameter less than the other two, may be united by nails or glue, the small one being placed in the middle, and they will form a very tolerable pulley, if bored in the centre so as exactly to fit the pin. If not sufficiently near true on the face, the pulley may either be turned with almost any tool that can be obtained, or the work may be accommodated to it by applying a greater thickness of cement on one side than on another. To prevent the pulley from grazing the wall, a small circular piece should be put on the pin before it, to serve as a washer.

The pole lathe, see fig. 17, pl. I. consists of two wooden, horizontal parallel cheeks, with a space between them for the insertion of the lower part or tenon of the puppets, and supported by legs or standards upon the same plan as the foot lathe. The puppets, of which there are only two, reach some inches below the chucks, and are fastened at any part of the

bed, by wedges, *n n*, passing through mortises near the lower ends of them. The mortises extend a little within the cheeks, otherwise the wedges would not draw the puppets tight. The puppet L contains a fixed point or centre, and the puppet M a moveable centre or regulating screw. Between these centres the work is supported. K is a long elastic pole, fixed at one extremity to the ceiling, and at the other attached to a cord which is coiled once or twice round the body to be turned, or round a pulley which carries that body along with it, and then passes on to the treadle, to which the lower end of it is fastened. The cord passes to the treadle on the same side that it came from the pole. It is of such a length, that when coiled round the work, the pole, if left to itself, will keep the treadle as elevated as the workman finds convenient. When the treadle is pressed down by the foot, the re-action of the pole elevates it again, the moment that pressure is forborne, and the backward and forward revolutions of the piece, round which the cord is coiled, necessarily follow.

As it is evident that the workman, in pressing down the treadle, has to overcome the resistance of the pole, the strength of the latter should not be more than sufficient to produce the immediate elevation of the treadle, otherwise he will uselessly waste his strength.

When the pole lathe is used, a groove for the cord must be turned at one end of the work as early as possible; or a perforated pulley may be placed upon the fixed centre, and the work connected with it in the manner already described for connecting the tool, fig. 6. with the chuck fig. 8. As simplicity of workmanship so generally distinguishes this lathe, a nail, of sufficient size, bent in the middle to a right angle, one end of it passing into a nick in the pulley, and the other driven into the piece to be turned, may be mentioned as a contrivance still more in character, and not unfrequently used by the humble provincial artist.

Though the pole lathe has been described, as it is generally found, made of the cheapest materials, and in the simplest manner, yet it must be obvious to the reader, that there is no impediment to its being made of metal, with all the excellence of workmanship so often bestowed upon other lathes, but that of incurring too much expense for a machine of circumscribed utility.

The rest mostly used to this lathe, is similar to that for the foot lathe, fig. 1.

Of the Tools used in Turning.

To describe the various tools used among the different descriptions of turners, would be impossible. They are so infinitely diversified in form and size, according to the necessities, the ingenuity, and often, no doubt, even the stupidity, of those who use them, that a volume would not suffice to do them justice. Mechanics are apt to consider the tools of their own invention the best of any, and this attachment, not to say bigotry, is often accompanied with a silly attempt to conceal from their neighbours the benefits of their *amazing* discoveries as to the best form of a chisel. But though we may not exhibit many of those peculiar forms of tools, upon which particular artists are disposed to pride themselves, we shall not omit those most essential and adequate to the execution of every description of work.

The handles of turning tools, it may be premised, must be varied in size according to the manner in which they are intended to be held. For heavy work, when the lathe is turned by machinery, or by men at the great wheel, they must be long enough to reach to the shoulder, upon which one end of them must rest in the act of turning, besides being held by both hands at the same time. In using the foot lathe, the tools are held by the two hands only, and their handles are seldom more than half the length necessary in the former instance. In using the hand lathe, as one hand is employed in turning the wheel, the handles of the tools need not be longer than what can be comprised in the other.

In turning wood, the *gouge*, fig. 13, pl. III. is the first tool used, as no other will so quickly reduce its irregularities. Its cutting edge is rounded; in using it, the rest is generally on a level with the axis of the work, and its handle is inclined downwards, so that its cutting edge is considerably above the axis. As gouges are made of all sizes, they are useful in making a variety of concave mouldings.

The *chisel* follows the use of the gouge; its cutting edge is oblique to its sides, and formed by bevelling both the upper and under surface, so as to make it in the middle of the thickness of the tool. In using it, the rest is elevated considerably above the axis of the work, so that, though held with a less inclination than the gouge, its edge operates on a higher part of the surface. The cutting edge of broad chisels is commonly made a little convex. The gouge and the chisel are the only tools held above the level of the axis; and the chisel is the only tool, the edge of which is formed by its being bevelled on both sides. Fig. 14. No. 1, is the front, and No. 2, the profile of the chisel.

Fig. 15, is a *right-side tool,* with two cutting edges, viz. a side edge and an end edge, so as to cut at once both the bottom and the side of a cavity. When it is used, the bevel which forms the edge is downwards.

A *left-side tool,* the side-edge of which is opposite to that last mentioned, is useful in smoothing the left external surface of spheres, and other rotund figures.

Fig. 16, the *round tool.* Though the gouge is generally used to form and sometimes to finish concave mouldings, yet, as it is very difficult, in whetting, to give it a regular convexity, the round tool, which may be formed with considerable exactness, is a useful assistant for the same purpose.

Some workmen chuse to have *point tools,* see fig. 17, for making nicks or small mouldings, as well as finishing the shoulders and flat ends of work; while others, instead of them, use the sharp corners and arrises of the chisels.

The tools included under the general term, *inside* tools, for turning out hollows and cups of all descriptions, exhibit the greatest variety of shapes, and exercise most the judgment of the artist, in suiting them to his wants. The forms exhibited in fig. 18, 19, 20, 21, and 22, are some of the most useful.

The *parting tool,* fig. 23, is used for making deep incisions, and cutting off any part of the work.

The drill, for making holes, is variously applied. It may be used along with the boring collar; or it may be screwed upon the mandrel, and the work held against it; or the latter arrangement may be reversed, and the work being fastened to a chuck, the drill may be held against it, while the tool is steadied upon the rest. The drill is sometimes formed so as to resemble half a hollow cylinder, but its section is a crescent, and its edges are moderately sharp. Its end is nearly like the mouth of a tea-spoon, and its hollow is greater than that of a gouge of the same breadth. This sort of a drill is used for small holes, but it is apt to turn so ill upon its point as to bore awry. The drill, fig. 24, is therefore used in preference, especially for large holes.

The use of the *outside screw-tool,* fig. 25, and the *inside screw-tool,* fig. 26, are explained in the section on turning screws. It is obvious that the work ought to be turned very true, before they are applied.

Turning gravers, triangular and *square tools,* with various other nameless sorts, the contrivance of individual skill, are used in turning hard bodies, such as bone, ivory, and metals. When the turning graver, fig. 27, is used, it is the first tool taken to iron and steel. The tool, fig. 28, of which No. 1 is the front and No. 2 the profile, is often used instead of the

graver, and cuts extremely well, but is not so easily managed with one hand. Triangular and square tools, are denominated from their respective sections being of these figures. They are flat at the end. The former have three cutting edges, viz. each arris in the direction of their length; the latter, which are mostly used for turning brass, have four, viz. each arris at the extremity. In a powerful lathe, the tool, fig 29, is a very useful one for iron.* It is flat at the end, and has four cutting edges, all alike. It cuts too keenly for a small lathe, and requires, besides, two hands to hold it; but with two hands, as one edge can be pressed upon the rest, it may be held remarkably steady.

To describe the use of the tool, fig. 30, may afford a familiar illustration of the advantage attending a proper adaptation of the figure of the tool to the work. It is intended to turn the flat heads of the small brass nails used in fastening the sheathing upon ships. These nails are little more than an inch long, and as a very trifling charge is made for turning the heads, the operation requires to be performed with proportionate expedition. A square hole, which just admits the shank of the nail, is made in the end of the mandrel; the nail is placed in this hole, the fly wheel set a-going, and the tool, fig. 30, applied so that the notch shall touch the rim, and the lower part of the tool the face of the head; then as the parts of the tool thus applied, have both cutting edges, the rim and face of the head are both instantly turned, while the nail is prevented from flying out of the lathe.—When one nail is done, another is inserted without stopping the fly wheel, and thus several hundreds may be done in an hour.

Of the Parallel Rest.

If a tool, opposed to any body revolving in a lathe, be drawn along, parallel to the axis of the mandrel, a cylinder will be produced; if it move in a line forming an angle with the axis of the mandrel, a conical figure will be obtained; and if it operate at right angles to the same axis, a flat surface will be the result. The machine in which a turning tool is fixed, to produce these effects, as it is frequently applied to the turning of parallel surfaces, has occasionally obtained the name of the *Parallel Rest.*

Fig. 31, pl. III. is a perspective view of the parallel rest, which must be wholly made of iron. It consists of two parallel cheeks, like a lathe, but the standards B B, are very short, as the whole height of the machine to the chisel F, must not be more than that of the axis of the mandrel from the bed of the lathe in which it is intended to be used. The standards, B B,

are firmly screwed to a strong plate C C, or, what is still better, cast in the same piece with that plate. The cheeks are united to the standards by four screws, in the same manner as those of the foot lathe already described. The lower part of the headstock D fits the space between them, in the most accurate manner, so that it cannot be thrown askew, but yet is not so tight as to prevent its free horizontal motion. If at any time it is found too slack, it may be tightened by a screw *a*, at the bottom of it.

The lower part of the interior side of each cheek is chamfered, and the plate through which the screw *a* passes, to act upon the headstock, slides between the chamfered portion of the cheeks. This arrangement is shewn in the section, fig. 32; *a* is the headstock; *b b* the cheeks; *c* the plate through which the screw passes, and in which there is no screw thread required; *d* the tightening screw. On the top of the headstock D, fig. 31, there is a rectangular groove for the chisel F, which is fixed in any part of it by a plate or cap on the top of the headstock. This plate or cap is fastened down by screws, passing perpendicularly through it; two screws, in this situation, are sufficient for a small machine, but four will be required for a large one.

To effect the horizontal motion of the headstock D, a screw E, the nut of which is in the standard B, is connected with it by means of a collar, and by turning the winch *b* of this screw, the motion required is produced. The screw must be long enough to push the headstock to the further end of the space between the cheeks, and it is advisable to make its thread a fine one, particularly when iron is intended to be turned with the machine, in order that the motion communicated to the headstock may with greater facility be made very slow and uniform.

In adjusting the machine to the lathe, the strong iron plate H I, fig. 33, is made use of. There are two wide grooves in it, *g g*, by which, with the help of two bolts, it is fastened upon the lathe, in the manner of a rest. The heads of the bolts must not project above the surface of the plate; therefore the grooves must be considerably wider at the top than the bottom, and the heads may then be countersunk. On the plate H I are also three immoveable cylindrical pins, *h i k*, all of them screwed at the top and fitted with nuts. In using the machine, the plate C C, fig. 31, is placed on the plate H I, fig. 33, so that the pins of the latter enter the apertures *l m n* of the former. The middle pin exactly fills the middle aperture, and upon it as a centre, from the width of the other apertures, the machine has, without moving the lowermost plate, fig. 33, a short range

back and forward, until the nuts in it are screwed down upon the upper plate C C, fig. 31. Now suppose a bar of iron, intended to be formed into a cylinder, be put into the lathe, let the machine be fixed so that its cheeks may be, as nearly as can be ascertained, parallel to the axis of the intended cylinder, at the left hand end of which place the tool so that it shall take off a slender shaving. Set the lathe to work, and slowly turn the winch *b*, till the tool has completely traversed the bar. Repeat the operation, if necessary, till the irregularities in the figure of the bar are removed, and the tool has touched every part of the surface; then, with a pair of callipers or a guage, examine whether the bar, at both ends, is of equal diameter; if any inequality appear, the rest has not been set parallel to its axis, and it, consequently, is not a cylinder. The matter is rectified by slackening the nuts of the pins *h i k*, and pushing in that side of the rest, which is opposite the thick end of the bar, just half the extent of the error. The nuts being then screwed down, and the tool made to traverse the surface again, the cylinder will be completed.

As it has been supposed that the bar was, in the first instance, by some oversight or other, turned rather conical, the method of making a regular cone with the parallel rest, when occasion requires, needs no explanation. When a flat surface is to be turned, it must be well secured to a chuck, the machine fixed across the bed of the lathe, and the cutting edge of the chisel F precisely on a level with the axis of the mandrel, or some part of the centre will remain unfinished. The tool may be made to cut with so much exactness, that if the face of a rectangular block of cast iron were attempted to be turned flat with it, the edges will not be jagged, when the circle of revolution, extending beyond the shorter diameter of the piece, is not complete.

When the chisel F, in the parallel rest, requires to be moved a little further in, some chuse to alter it by percussion, and keep it only so tight that the blow of a moderately sized hammer will drive it in; others think it better to regulate it by a screw, and provide a frame for the back of it, similar to that at the back of the puppet D, fig. 13, pl. I. in which the screw *a* acts upon the end of the mandrel.

The section of the cheeks of the parallel rest, to abridge the labour of filing, may be made to resemble that proposed for the cheeks of the foot lathe, fig. 2, pl. I.

Of cutting Screws in the Lathe.

The art of cutting screws in the lathe, constitutes one of the most curious and useful branches in the art of Turning. Accordingly, it generally proves one of the most interesting exercises to the young practitioner, who is further stimulated by the celebrity of those who can cut every description of screw with facility,—an attainment commonly considered, among turners, one of the most decisive proofs of skill that can be exhibited.

In proportion as the art of cutting screws has been cultivated, the methods by which the object might be accomplished, have been diversified. We shall notice some of those contrivances which are least expensive, most easily reducible to practice, and most suitable for general use.

If the screw-tool, fig. 25, be opposed to a cylinder revolving in a lathe, and at the same time be moved along the rest, with a regular horizontal motion, it will cut a screw on that cylinder, the threads of which will fill the angular spaces between the teeth of the tool. Fig. 25, is an *outside* screw-tool; if the cylinder had been hollow, and intended to be screwed internally, the *inside* screw-tool, fig. 26, must have been employed, which, when pressed against the side of the cavity, while drawn out horizontally as the cylinder revolved, would have produced the desired effect. There is some difficulty in acquiring the art of cutting screws in this manner, though the process is in very general use among experienced turners. To obviate every disadvantage which attends it, and ensure perfect precision in the operation, was the object of the invention of the traversing mandrel. Of this ingenious contrivance, we shall next, therefore, endeavour to give the reader a description. At the end of the mandrel E, at *e*, fig. 1, pl. I. there is a screw about two inches long, the thread of which is like that intended to be made. Upon this screw, called the guide, is fitted a piece of wood, the motion of which is entirely prevented by any mode of fastening which may be found convenient. The piece of steel on the headstock C, which falls into the groove of the mandrel, and hinders its horizontal movement, being then withdrawn, and the great wheel turned, the mandrel assumes at once a rotary and rectilinear motion, which is continued till it has gone so far, that the screw *e* can no longer turn in the piece of wood. If, as soon as this circumstance occurs or a little sooner, the great wheel be turned the contrary way, the rotary and rectilinear motion of the mandrel immediately takes place again, but in a reversed direction. This

compound motion of the mandrel, is precisely what is wanted to facilitate the use of the screw-tool, which, while it is going on, only requires to be held steadily upon the rest, against the revolving body, and the screw will be produced. The teeth of the screw-tool must correspond with the screw upon the mandrel, as if it had been made by holding it against that screw revolving in a lathe.

It is customary to cut three or four screws, of different threads, one behind another, upon a traversing mandrel, as a single one would only be of limited use. But even as three or four screws are often insufficient to meet the wants of the artist, and the length of so many together is awkward and inconvenient, it is better to make a concave screw in the end of the mandrel, to which any variety of convex or guide screws may then be alternately attached.—The revolution of the guide screw, without the mandrel, may be prevented by a screw *z*, near the end of the latter.

In cutting screws, the proper motion cannot be communicated from a fly wheel to the mandrel by means of the foot acting upon a treadle. If a fly wheel be used, it must be turned backwards and forwards by a winch, through a space proportionate to what the guide screw will allow, so that two persons will be required for the operation. But to cut screws in a foot lathe, the fly of which is unprovided with a winch, and to render one person adequate to the performance, a cord descending from a spring, as in the pole lathe, is coiled round the pulley of the mandrel, and attached to the treadle, the range of which may be suited to the occasion.

With respect to the mode of fastening the wood in which the guide screw turns, a word may be expected. Let a stock or horizontal piece, *w*, be screwed to or cast along with the head-stock C; let the end of it be tapped to receive the screw *x*, which must be taken out previously to fixing the wood upon the guide screw *e*. When the wood is in its proper place upon the guide, it must hang down over the end of the stock *w*, and there must be a hole in it just large enough to admit the screw *x*, by which it can then be made perfectly secure.

The use of the traversing *mandrel* will probably in a little time give way to that of the traversing *chuck*, which was invented by Robert Healy, A. B. of Dublin, and a description of it, communicated by him, inserted in the Philosophical Magazine. On the common mandrel A, fig. 1, pl. IV. is screwed the chuck B, to which may be screwed the chucks of the lathe, as R. On the outside of this chuck B, is turned a screw, which is fitted to an inside screw worked in the circular block C, from which block extends an arm D,

as long as may be thought fit for the purpose of permitting another arm E, to slide up and down it; a piece of iron should be screwed to the circular block C, of such a length as to be capable of moving in a groove that may be cut in the collar, or adapted to it. This piece of iron should be regular in its shape, and well fitted to the groove; it is intended to prevent the block C, from being turned round, and to allow it only a steady rectilinear motion. The rest, G F O, must not stand as usual parallel to the work, in cutting an outside screw; but at right angles, as when an inside screw is to be cut, in order that the further arm of the rest F, may be joined to the end of the second or intermediate arm E. It is necessary that this second or intermediate arm E, be capable of fastening firmly the first arm D, to any part of the rest, G F; it must also have a joint at each end to admit, in a horizontal plane, its free play. Thus, as the lathe turns to us or from us, the arms must traverse forwards or backwards; which gives a similar motion to the tool H, that is held steadily or fixed with a screw on the further arm F, of the rest; and thus a screw is cut with a tool of a single point. It is unnecessary to mention, that no joggling should arise from the motion of the arms, as that would cause a failure in cutting a perfect screw. If the centre of the rest should be drawn nearer to us, and by that means bring the tool closer to the intermediate arm E, then a screw of a much larger size will be cut; for as the rest, turning within its socket (the thumb-screw for fixing it in the pillar, being in this operation always withdrawn,) moves on a centre, the further the tool is moved from this centre, the greater will be the radius of the circle described, and consequently the coarser will be the screw; and, *vice versâ*, the nearer the tool is brought to the centre, the smaller will be the radius of the circle, and thus the screw will be finer. Should the intermediate arm E, be connected with the nearer arm of the rest G, and the tool held on the further one F, then a left-handed screw will be cut, of a thread the distance between the turns of which will vary according to the distance of the point at which the tool is held between the centre and extreme end; for, as the lathe turns to us, the arms receive a forward motion, except the further arm F, of the rest, which receives a backward motion; but when the lathe turns from us, then the further arm receives a forward motion; and as the tool meets the wood, so it cuts a left-handed screw.

It may be apprehended that a piece of wood so far removed from the collar K, might spring its motion; but this may be obviated by not making use of the traversing chuck B, till the

screw is to be turned; for as the cutting of it is light work, there will be little resistance, and, of course, but little spring; or the traversing screw, B, may be turned on the mandrel A. Another disadvantage would seem to arise from the impossibility of cutting screws when the puppet head is made use of, to prevent the springing of a long piece of wood. But this may be obviated by lengthening the intermediate arm E, to the part where we intend cutting the screw, and thus we have the same screw as that of the traversing one: if a finer or coarser screw should be required, then, by having an arm of the rest to slide in and out, and the intermediate arm to be connected with the centre of the rest, we have just the same power of turning screws as in the former case. A socket S, is represented, the lower part of which slides on the rest, and may be fastened firmly to it by a screw: the upper part, that turns on a pivot, admits the intermediate arm to slide through it, which arm is held stationary in it by a screw.

If the rest were to make a right angle with the piece of wood on which the screw was to be turned, at the commencement of the process, and to become parallel to it when the screw was finished, an approximation would take place from a larger thread to a smaller, or *vice versâ;* but it is impossible for the rest to become parallel to the work, from the connection of the arms. Now let the traversing arm D, lie in the centre of the screw B, on which it plays, and let the rest make a right angle with the wood on which we intend to cut the screw. The rest may traverse thirty degrees on either side of the right angle; which will not cause any sensible approximation in the thread, and will admit a motion sufficiently extensive for turning the common length of screws. But as the method answers for a short screw of a few turns, that is sufficient for every purpose; for, in order to make a long screw, there may be three different ways of accomplishing our object:

1st, At the commencement, the rest stands at right angles with the wood on which the screw is to be cut; by its describing an arch of a few degrees, a short screw is cut; then by bringing back the rest to its original angle, the right one, and sliding forward the single pointed tool to the last thread of the screw that was just cut, we proceed to any length by repeating the same process.

2ndly, When one or two threads of a screw are cut by making use of a common screw tool, the most unskilful hand will be able to continue the screw to any length.

3dly, Should a side tool with many teeth, instead of the single pointed one, be made use of, a screw of any length may be cut, the rest describing its usual arch.

Elliptic Turning.

Pl. II, exhibits perspective views and elevations of the apparatus for elliptic, or (as it is vulgarly called) oval turning. An oval is smaller at one end than the other, like an egg, and therefore differs essentially from an ellipse. In all the different figures, 1, 2, 5, 6, 7, and 8, the same letters refer either to the same things, or to corresponding parts of the machine.

Fig. 1, is a front view of the machine. I K is the principal iron plate, to which all the subordinate parts of it, except the ring, (afterwards described,) are affixed. A short screw W, is riveted or soldered to this plate, upon which the material to be turned must be fastened, either with or without the intervention of a chuck, as the nature or form of it dictates. This screw, to raise the back or lower part of it above the level of the plate I K, has a shoulder, which affords a useful bearing to whatever is screwed upon it, and prevents the inconvenience which would otherwise arise from the projecting heads of the screws *x x x x*.

Fig. 2, exhibits the various parts of the machine on the back of the plate I K, at each of the four corners of which there is a short square pillar, on the summits of which are placed the letters of reference, *d d d d*. Within these pillars, are placed two narrow side ribs or pieces of steel, *f f*, which reach the whole length of the plate I K. Each of these pieces, on the side opposite the other, is bevelled, so that when placed on the plate it forms an angular groove in the direction of its length. The two angular grooves formed by the pieces *f f*, are filled by the chamfered sides of the slider E F, which is capable of a free longitudinal motion between them. When the slider has been put in its place, two end ribs or pieces of steel *m m*, are placed within the pillars, *d d d d*, parallel to each other; they bear upon the side pieces *f f*, to which, and to the plate I K, they are firmly held by the screws *x x x x*. The nut L, is cast in the same piece with the slider E F; in using the apparatus, it is screwed upon the nose of the mandrel, and its size must accordingly be proportioned to the mandrel, for which it is intended. When the end pieces, *m m*, are fixed, the slider cannot be thrown out of its situation in the grooves, as they limit its only motion, the longitudinal one to the space between them, because the nut L acts as a stop, at either end to which the slider may be impelled. This effect, however, though a necessary consequence of the construction, is not essential to the excellence of the machine; the principal use of the end pieces, *m m*, is of a different nature. The space between them is exactly equal to the diameter of the ring O P, fig. 3, upon

the outside of which they revolve, when the nut L is screwed upon the mandrel. Two arms, R S, are connected with this ring, and in each of them there is a groove, nearly their whole length. These grooves are exactly straight and opposite each other, and a line carried from one to the other, along the middle of them, would intersect the centre of the ring. The projection of the ring above the arms, is clearly shown by the elevation, fig. 4.

The elliptic machine is connected with the lathe, and its peculiar motion obtained in the following manner: let E F G H, fig. 9, represent the upper part of a headstock, through which two holes have been drilled, at a little distance from the collar, the centres of which holes are precisely in a line with the centre of the mandrel M; let the ring be fastened to the headstock by means of two screws *t t*, with button heads, the shanks of which pass through its grooves, and through the two holes made in the headstock, at the back of which they can be drawn tight by nuts. When the ring is in this situation, it will be perceived, that it can only be moved from side to side, and its centre, from what has been said of the position of its grooves· and that of the holes through which the screws that fasten it pass, must always be in the same horizontal line with that of the mandrel. Tighten the nuts of the screws *t t*. Now let the apparatus A B C D, fig. 2, be united to the mandrel, by screwing upon it the nut L; the inner surface of the end ribs or pieces *m m*, will fall at the same time upon the outside of the ring. The plate I K, if the ring have been set so that its centre exactly coincides with that of the mandrel, will, when motion is communicated to it, revolve in a circle; but if the centre of the ring be in the smallest degree on one side of that of the mandrel, it will revolve in an ellipse, the difference between the conjugate and the transverse, or long and short, diameters of which, will be double the distance between the centre of the ring and that of the mandrel. When, therefore, the work is fastened to the screw W, as in common turning it is to the nose of the mandrel, it becomes as easy to turn an ellipse as in other cases it is to turn a cylinder.

The slider E F ought to move with great steadiness, and at the same time with freedom;—requisites which cannot be combined without considerable accuracy of workmanship. To obtain an easy mode of making the wearing parts of the machine fit, and also to lessen the friction in some degree, several little arrangements are made, to some of which it may not be improper to advert. The slider is made of bell-metal, or a composition similar to that already recommended for the collar of a lathe, and only a narrow strip on each side of it touches the

back of the plate I K; these narrow surfaces of friction are shown by a lighter shade of the engraving, on the right and left of E, fig. 1; the rest of the surface is cast about the twentieth part of an inch lower than these strips, and it therefore requires but little labour to make the slider true. The other or upper side of the slider E F, fig. II, is not so thick as to touch the end ribs, *m m*, when sliding under them.

In each of the four plllars, *d d d d*, are two screws. Four of these screws, *n n n n*, press upon the end ribs *m m*, which, by screwing them in, can at any time be brought nearer to each other, for the purpose of correctly fitting the ring. The side ribs, in like manner, to embrace the slider tightly, may be brought nearer to each other, by the four other screws, only two of which, *r r*, can be seen in fig, 2. The four screws, *x x x x*, the square heads of which are seen in fig. 1, and their ends in fig. 2, are screwed only into the end ribs *m m;* they are rather smaller than the holes in the plate I K, and those in the side ribs, *f f;* through which they pass, otherwise the screws in the pillars would not enable us to drive the ribs further in.

Fig. 5, and 6, are two elevations of the machine, which exhibit the form and relation of some parts of it to each other, more clearly than the perspective views. Fig. 5, is the side, and fig. 6, the end of the machine. The same letters of reference being, as previously observed, placed upon the same things, the position of which only is varied in the different figures, much further description would be superfluous. It may be observed, however, that fig. 6, shows distinctly the bevel given to the sides of the slider E F, as well as that given in a contrary direction, to the side ribs *f f*, in order to form the grooves which receive the slider.

Fig. 7, represents one of the side ribs, and fig. 8, one of the end ribs, separately.

The form given to the ring, fig. 3, though eligible for a small machine, would be unsuitable for a large one. The limit of its propriety is determined by the breadth of the puppet for which it is intended; it cannot be wrong, when the puppet is broad enough to admit the holes for the screws *t t*, fig. 9, to be placed so as to allow the ring its full lateral range, in which case it can be brought close up to the mandrel. But when the shape here delineated is inadmissible, the grooves or openings for the screws, may be formed within the ring, by two stout ribs on each side of its centre, and it may then be fastened to a puppet of the customary dimensions.

Miscellaneous Remarks on Turning.

The parallel rest, already described, is similar in principle to a machine invented by Earl Stanhope, for turning flat surfaces. This patriotic Nobleman found, that the method of stereotyping invented by him, as well as that construction of the printing-press which is distinguished by his name, could not be carried to the perfection he had in view, without devising some method of making large surfaces of cast iron accurately flat. He has always had in view the important object of rendering the successful application of his inventions as independent as possible of manual dexterity; and, accordingly, the rest or tool which he has invented to perfect his stereotype labours, is, if we judge by its effects, and the manner in which it is wrought, commensurate at once to his genius and his wants. Massive blocks of iron, presenting a surface of eight or nine square feet, are turned by it with wonderful facility, and with a degree of exactness which will probably never be exceeded. It is, like the parallel rest, peculiarly adapted to the turning of metals, and doubtless exceeds, in the excellence of its performance, every thing of the kind before attempted.—Of the contrivances which have been adopted to facilitate, upon similar principles, the expeditious and correct turning of wood, that by Smart, of Ordnance Wharf, Westminster, deserves particular notice and approbation. The apparatus which this ingenious mechanic has invented, is used in his manufactory, and when applied to a common lathe, enables one man, with the assistance of two labourers at the great wheel, to turn six hundred poles, each of them a very accurate cylinder, and five and a half feet long, in the course of twelve hours. His mandrel revolves twelve hundred times in a minute, in which short space of time one pole is finished. The means by which he attains his object, have the merit of not only being efficacious, but of possessing great simplicity. The gouge for roughing out the work is fastened in a block, or cutter-frame, which is nothing more than a piece of wood, containing a cylindrical hole, large enough to be shoved over, without touching, the work to be turned. The gouge passes through the block into this cavity, where its edge projects, just as the blade of a joiner's plane projects from the bottom of the block in which it is fixed. The chisel, which succeeds the use of the gouge, is fastened in another frame of a similar description. The gouge and chisel are held in their respective places by screws. The remaining part of the apparatus consists of two strong wooden cheeks; and as these must always be as long as the work, it is best to make them, at once, the full length of the bed of the

lathe, measured from the middle puppet. They may form a separate frame, or they may be fastened one on each side of the middle and right hand puppets, parallel to one another, and their upper surfaces in the same horizontal plane. Their position will then be similar to that of the cheeks of the lathe itself. To give them additional steadiness, if found necessary, they may be supported, in one or two places, by feet resting upon the lathe, or by short puppets of sufficient breadth to reach under them. On the bottom of the gouge and chisel frames, there are two grooves, the same size and distance from each other as these additional cheeks, which they are intended to admit into them. The cheeks must be of such a height, that the cutter-frames can be slidden along upon them, with the axis of the holes, into which the gouge and chisel project, coincident with the axis of the mandrel, and consequently coincident with that of the work. The projection of the mandrel, and that of the screw in the right hand puppet, is always rather more than the breadth of both the cutter-frames together, in order that the latter, when in use, may be made entirely to clear the ends of the pole. At the commencement of the process, after the cheeks upon which the cutter-frames slide have been fixed, let the cutter-frames themselves, (that containing the gouge being outermost,) be placed against the right hand puppet, the screw of which, if far enough out, will then extend through the centre and a little beyond them. The pole to be turned, which we will suppose already prepared, by hewing it octagonally, or somewhat rounding it, is fixed to the lathe in the customary manner, and the gouge frame, the men having begun to turn the great wheel, is pushed along its whole length; and the tool being previously adjusted so as to take off a shaving of sufficient thickness, as soon as it has cleared the end of the pole, it is left over the mandrel. The chisel frame is next pushed along in like manner, and thus it is that one minute suffices to complete a very smooth and accurate cylinder. It is obvious, that the best position for the gouge and chisel in their frames, will be that which gives each of them the same inclination to the surface of the work, that is found most advantageous in turning by hand. This mode of turning may be classed, perhaps, among those inventions, which every one requiring their aid is apt to wonder he has not thought of, or to believe that he could have thought of; and the very simplicity of which, while, instead of disparaging, it enhances their value, and the debt which the public owe to their authors, is one of the main obstacles to the discovery of them.

A numberless variety of figures may be produced in the

lathe, by regulating the action of the tool, in its advance to, or recess from, the face of the piece exposed to its action. Medallions, and other similar pieces, have been executed by enthusiasts in the art, who have spared neither expense in procuring the necessary apparatus, nor patient perseverance in the use of it. In the British Museum, there is a profile in bass-relief, of Sir Isaac Newton, wholly made by turning; the resemblance is considered very correct, and the place in which it is deposited may be considered a sufficient proof of the difficulty with which it has been executed.

Watch-cases, snuff-boxes, and various sorts of trinkets, are sometimes formed by what is called rose-work. Plates of iron or brass, indented or waved on the edge, in any curve or form which may be desired, are screwed upon the mandrel. These plates, which are called roves, serve as guides to regulate the action of the tool, in producing a correspondent form on the work.

The copper cylinders used at Manchester in printing calicoes by machinery, afford specimens of turning, or rather of engraving in the lathe, of the most curious and interesting kind. No production of the art can be more beautiful than the workmanship of many of them, nor more admirable than the effect produced by their use. A whole web or piece of calico is printed by them in three minutes. They are, in the first place, turned accurately cylindrical, and polished with as much care as the copperplates for common engraving; the pattern is then cut upon them, and it is this part of the process, in preparing them for use, which most remarkably exercises the genius of the artist. Two methods of executing it present themselves—the graver and the lathe. As the latter, for every pattern to which it can be applied, is so much more expeditious and accurate than the former, a desire to make use of it in preference naturally follows; and accordingly it is made use of in cutting a vast variety of beautiful patterns, to the production of which few would consider any tool but the graver, directed by the most complete manual dexterity, in any degree adequate. The identical methods pursued by different artists, in this branch of turning, are but little known, but a general idea of the nature and possibility of the thing is not of difficult comprehension. Let the pattern intended for the copper be cut upon the circumference of a small steel wheel, which must be made to revolve upon an axis. Let this wheel be held against the copper cylinder, which, when revolving in a lathe, will carry it round, and receive from it an impression of the pattern on its circumference. When one ring of the pattern impressed by the wheel has been obtained, it is plain, that by repeating the

operation, others may be made at any required distance from each other. As the wheel operates almost like a punch, the marks made by it are seldom square at the edge; but these inequalities are soon reduced by the common process of turning and polishing. It may also be observed, that the cavities made by the wheel must be left rough or notched at the bottom, in order that they may better retain the ink till they meet the calico. To cut the wheel, so as to produce this effect, facilitates its entrance into the cylinder.

Practical directions for turning might easily be multiplied, but the necessity for much further minuteness of detail will be removed by a little observation and experience; yet we are unwilling to refuse a place to a few remaks which may be acceptable to the novice. In turning a hollow sphere, the convex surface is first completed, and then perforated with a centre-bit to admit of the tool, fig. 20, pl. III, by which the interior may be cut away. But as it may not be desirable to make a very large hole for the admission of the tool, it is customary to perforate the sphere in six places, each hole being made in a direct line to the centre, to which they must all approach within half their diameter. They are also bored at equal distances from each other, and each hole is at right angles with all the rest except one, to which it is exactly opposite. Hence the points at which these holes ought to be made, may be obtained by drawing circles upon the sphere which divide it into quarters; the points of intersection of these circles, are the places sought. Place the sphere in a chuck, with the axis or middle of any two of the holes in the same line with that of the mandrel. Turn out a portion of the interior from the hole in front; then in succession bring every other hole to the front, and proceed in like manner. The partitions dividing the several excavations will at length be cut through, or will be made so thin that they may be cut from the interior surface of the sphere by a bent saw.

To turn one sphere within another, cylindrical holes as in the last case are required, but the thickness left between each pair of opposite ones, must at least be equal to the diameter of the inner sphere intended to be left. The tool, fig. 21, or that fig. 22, is used to make the excavation or space between the concentric surfaces, by entering in rotation, as before, the six holes. By using the tool represented by fig. 18, or that of fig. 19, a cube might have been turned instead of the inner sphere.

To turn a series of spheres within each other, the depth of the cylindrical holes must be such as to leave the thickness between each pair no more, or but very little more, than the

diameter of the smallest sphere intended to be left. With forming this innermost sphere, the operation may be most properly begun, and afterwards continued in regular progression to the larger, till at last the one next the exterior sphere is completed. If it be thought desirable, the spheres may have their cylindrical holes proportioned to their respective sizes, by boring at first a little way with a large centre-bit, and afterwards using a smaller and a smaller one, in approaching the centre.

When the band of a lathe is crossed, and the wheel is turned with great velocity, it is apt to wear by rubbing against itself. This effect may be prevented by interposing a pulley at the crossing place. The pulley may turn upon a pin at the end of a piece of wood rising aslant, and attached to the cheek of the lathe, or fastened to the floor.

The number of turns which the mandrel ought to make in a given time, must be varied according to the nature of the material in the lathe. The velocity of rotation, for wood, can scarcely be too swift; it must be rather slow for lead, pewter, brass, and bell-metal; still slower for cast iron, and slowest of all for forged iron and steel. The reason for these limits appears to be, that a certain time, varying with the material, is requisite for the act of cutting to take place, and that the tool itself, if much heated, will instantly become soft, and cease to cut. In a lathe turned by the foot, three turns of the pulley of the mandrel, for one of the fly wheel, will be found sufficiently quick for iron; four or five turns of the pulley, for one of the fly, may be allowed to brass; and ten or twelve will not be too much for wood. As, however, in turning a large fly wheel very slowly, to produce the required slow motion of the mandrel, would occasion the loss of the power accumulated by its increasing momentum when swiftly revolved, a small wheel may be placed on the same axis. This small wheel may receive the band, and the size of it may be so proportioned, that it may be turned with the large one as swiftly as we please, without making the velocity of the mandrel too great.

The temper of the tools employed in turning iron and steel, when they are annealed, is not commonly higher than purple. But when the inequalities of steel have been reduced, and it is required to cut it extremely clean, the use of a sharp hard tool will be advantageous. Steel and cast iron at a high temper also require a very hard tool, and the angle forming the edge of the tool must be considerable; if equal to seventy or eighty degrees, it will not be too obtuse. Steel and iron are cut more freely, if kept constantly wetted with water, or thinly covered with oil or tallow.

When iron and steel are to be turned in a small lathe of little power, as soon as the work is fixed, it is with many a practice to nick it all round with a graver, in one or two places; if the nick be deeper on one side than another, a file is employed to make it every-where alike; and when this has been done, the power employed to finish it may be very inconsiderable, without much loss of time.

The bank, or upper part of the rest, upon which the tool is held, is short, broad, unpolished, and very strong for metallic work, in order that the tool may be steadied upon it in the most effectual manner; but in turning wood, it is long, narrow on the top, and polished, so that the tool can be swiftly glided from end to end. To a foot lathe, the bank of the rest, for metal, is seldom made more than three inches; while for wood its length is twelve or fourteen inches. In turning bed-posts and other things of great length, a piece of wood, the whole length of the work, is made use of as a rest, to prevent the trouble of those frequent removals which the common rest would require. With a like view of saving time, the rest, for globular work, is often made of a semi-circular form.

When the work is too long and slender to bear the action of the tool without yielding, it is supported in its proper place, from the back, by a frame, which, like the rest, can be fixed in any situation, and carries an arm with a semi-circular excavation in front. This opening admits the work, to which it is brought close up, and which it prevents from being bent or broken by the tool.

When the material which has been turned is wood, and it has been made as smooth as possible with the chisel, or other edge-tool which its peculiar form may have required, it may be polished with shark's skin, or Dutch rushes. The shark's skin, being obtained from different species of that fish, is sometimes of a reddish and sometimes of a dark grey hue, without any material difference of quality; it is too rough for polishing at first, and therefore must be worn a little by using it to the rougher states of work, before it is applied to this purpose. The Dutch rush is the equisetum hyemale of Linnæus; it grows in moist places among the mountains, and is remarkable for having flinty particles in the substance of its leaves, which render it so useful in polishing. It has a naked, simple, and round stem, about the thickness of a goose quill. The oldest plants are the best. Before they are used, they should be moistened a little with water, otherwise they presently break, and become almost useless. The use of the rush is particularly proper for hard woods, such as box, lignum-vitæ, or ebony. After having well smoothed up the work, it should be rubbed

gently either with wax or olive oil, then wiped clean, and finished by rubbing it with a cloth or its own shavings.

Ivory, horn, silver, and brass, may be smoothed with files, or with pulverized pumice-stone, laid upon leather or a cloth a little moistened. When a very fine surface is required, tripoli, and afterwards oxide of tin, may succeed the use of the pumice-stone. To polish iron and steel, after they have been made as smooth as possible with files, very fine flour of emery is mixed with oil, and laid upon two pieces of soft wood, between the surfaces of which, thus coated, the work is pressed and made to revolve.

Of TIMBER.

From a view of the properties, uses, and principal modes of working the metals in most common use, we now proceed to details of a similar kind respecting timber. One description of the mechanical operations belonging to this subject, have, indeed, already been anticipated by the sections devoted to the mixed art of Turning, to which both wood and metals are alike extensively subjected; but much yet remains to be adverted to, which forms a proper part of the knowledge of the turner, though more particularly subservient to the purposes of the carpenter, the joiner, the millwright, and the cabinet-maker. We shall commence with an enumeration of the most useful sorts of wood, with a few remarks on their properties, their uses, and the best methods of seasoning timber in general.

Of all the different kinds of timber produced in this country, *oak* is the best for building, and for almost every purpose of rural and domestic economy, particularly for staves, laths, and spokes of wheels. Even when it lies exposed to air and water, it is preferable to almost all other woods; and as it is, besides, hard, tough, tolerably flexible, and not very apt to splinter, its excellence for ship-building is unequalled. Its quality is improved, if the tree be suffered to stand three or four years after it has been barked, as it thus becomes perfectly dry; the inspissated sap renders it much stronger than the heart of those trees which have not been stripped, and its hardness, weight, and durability, are also increased.

Beech is also a wood of great utility; it is very tough and white when young, and of great strength; but liable to warp very much when exposed to the weather, and to be worm-eaten when used within doors. Its greatest use is for planks, bedsteads, chairs, and other household goods; and for these purposes, it seems almost as necessary to the cabinet-makers

and turners of the metropolis, as oak is to the ship-builder. The worm by which it is so liable to be destroyed, is supposed principally to feed on the sap that remains in the wood, consequently the best method of preserving it, is to extract the food on which the worm subsists. For this purpose, scantlings of beech, when large, should be laid to soak in a pond for several weeks, according to the size of the timber, and the season of the year. In the heat of summer the desired effect is more speedily produced. Generally, beams and thick planks should remain about twenty weeks in water; joists and rafters about twelve weeks; and the thinner boards about two months. As the planks or boards are in danger of warping, when exposed to dry, they should be sheltered from the sun and rain; laths ought to be placed at intervals between the boards, to prevent their contact, and the whole pressed by a considerable weight. If they are large pieces, for beams, joists, &c. They need only be left to dry gradually under sheds. Beech, by these means, will be rendered as good and durable as elm; but when it is used for building, it is advisable to prepare that part of the timber which touches the brick-work with a thick coat of pitch, to guard it against the effects of moisture. If the wood have been felled in the heat of summer, the sap, of which it is then full, may be more readily extracted than if it be felled in winter. When this wood is intended for small work, such as chairs, turnery, the handles of saws, and the blocks of joiners' planes, it is recommended to boil it in water for two or three hours. This mode of preparing it extracts all the sap; makes it work more smoothly; and renders it more beautiful and durable.

The consumption of *elm* is very considerable; it is very tough, pliable, and the best kinds of it are very hard; it does not readily split, and bears the driving of bolts and nails into it better than any other wood. It is used for making axletrees, mill-wheels, keels of boats, water-pipes, chairs, and coffins. It is frequently changed by art, so as to make an excellent resemblance of mahogany. For this purpose, planks of it are stained with aquafortis, and rubbed over with a tincture, of which alkanet root, aloes, and spirit of wine, are the principal ingredients.

Wild chesnut timber is very durable, and is by many esteemed as good as oak. It seems to have been much used formerly in building; it excels oak in two respects, namely, it grows faster, and the sappy parts of it are more firm, and less liable to corruption. At the age of eighteen or twenty months, it may be cut for hop-poles, for which it is very serviceable. It is superior to elm for jambs, and several other purposes of house-carpentry; but on account of its possessing a precarious

brittleness, which renders it unsafe for beams, it ought not to be employed in any situation where it will have to support an uncertain weight or strain. Perhaps this is the principal reason why it has rather fallen into disuse for building. It is generally agreed, that it is peculiarly excellent for casks, as it neither shrinks, nor changes the taste or colour of the liquor. It is often converted into articles of furniture, and may be made to imitate mahogany, by rubbing it over with alum water, then brushing it with a hot decoction of logwood, and lastly with a decoction of Brazil wood.

Ash is a very useful wood, which possesses the very remarkable property of being almost equally good, whether cut young, or at full maturity. It is tough, hard, and more elastic than most woods. It answers well in buildings, and for any other use, when screened from the weather. It is much used for making implements of husbandry, particularly hop-poles, also for handspikes, oars, and the handles of tools, such as the axe, adze, &c.

Walnut-tree is excellent for the joiner's use, and was in great request for all the best articles of furniture, till superseded by mahogany; it is still in repute for the best grained and coloured wainscot; with the gunsmith, for stocks; with the coach-maker, for wheels and the bodies of coaches; with the cabinet-maker, for inlayings, especially the firm and close timber about the root. To render this wood the better coloured, joiners put the boards into an oven, or lay them in a warm stable; and when they work it, polish it over with its own oil very hot, which makes it look black and sleek. The oldest wood is the most valued.

The *wild pine-tree*, called in this country the Scotch fir, from its growing naturally in the mountains of Scotland, furnishes the best red or yellow deal, so much employed in the making of masts, floors, wainscots, tables, boxes, and for numberless other purposes. The wood is very resinous, and the most durable of any of the kinds of fir yet known. The wood of the black and white spruce firs, is very light, and decays when exposed to the air for a considerable length of time; it is chiefly employed for packing cases, musical instruments, and the like.

Deals, or common fir boards, may be much hardened and improved, by immersing them, as soon as they are sawn, in salt water for three or four days, care being taken to turn them frequently during that time. They should then be dried by exposing them to the sun and air; but neither this, nor any other mode of preparing them yet known, will prevent their shrinking. The shrinking is greatest transversely; in the

direction of the length of their fibres, when once well seasoned, they shrink so little, that a piece of deal is highly esteemed for the rod of a pendulum.

The timber of the *larch-tree* is possessed of many very valuable properties. It is exempt from the depredations of worms; it is peculiarly calculated for ships' masts and the building of vessels, or for strengthening the wooden framework of bridges; for it is capable of supporting a much greater weight than the oak itself, and almost petrifies under water. It also resists the influence of our climate, and is excellent for gates, pales, shingles, and other works which are exposed to all the vicissitudes of the weather. Houses constructed with larch timber, have a whitish cast for the first two or three years; after which the outside becomes black, while all the joints and crevices are firmly closed with the resin extracted from the pores of the wood by the heat of the sun; and which, being hardened by the air, forms a kind of varnish, not inelegant in its appearance. Buildings constructed with it, have been observed to remain sound two hundred years. No wood affords more durable staves for casks, and the flavour of the wine is at the same time preserved. The charcoal made from the larch is not only much superior in quality, but in quantity, to that made from a like measure of the fir-tree.

The *common cedar* (of Lebanon) is a species of the pine-tree. The character of its wood is well known, and firmly established. Its uniformity and softness recommends it to the use of the manufacturer of black-lead pencils; while its neat appearance, and its not being liable to the depredations of worms, occasions a great demand for it from the cabinet-maker, for the drawers and interior divisions of desks, &c. where great strength is not required. It is admirably calculated to withstand the effects of moisture.

The different species of *poplar trees*, supply timber much used instead of fir; it looks better, and is tolerably tough and hard. Poplar wood is not very subject to the ravages of worms, nor to warping or shrinking. It is advantageously employed for wainscoting and floors, as well as for water-pipes, packing boxes, and turnery wares. For bedsteads it is deemed unsuitable, as it is considered more liable than other woods to be infested with bugs. It is a very incombustible wood, and therefore admirably adapted for the floors of workshops where ignited bodies are apt to be thrown down.

The wood of the *birch* or *alder tree*, differs not very materially from that of the poplar, either in quality or use. The

soles of what are called wooden shoes, and women's shoe heels, are made of it. It is also much used for hoops, and by the turner, for bowls and dishes of all sorts.

The whitest and finest kinds of *maple*, are used by cabinet-makers for inlaying. On account of the lightness of this wood, it is frequently used for musical instruments. It is excellent for the use of the turner; cups made of it may be turned so thin as to transmit light. These characteristics belong more particularly to English maple, which is also well known under the name of *sycamore* or plane tree, and when grown on favourable situations, is almost as hard, white, and beautiful, as holly. The American maple is mostly of a dull light brown colour; it is a softer wood, and its grain has some slight resemblance to that of the cherry-tree.

Pear-tree wood is smooth, light, and compact; very suitable for the turner's use, and when stained black, makes a good imitation of ebony, for picture frames, and similar articles. It is sometimes engraven upon, but for this purpose it is much inferior to box, and even to holly.

The wood of the *cherry-tree* is smooth, tough, yellowish, with a grain like the commoner kinds of mahogany, of which, with a very little assistance from staining, it makes an excellent imitation. It is therefore used for the middling qualities of furniture, by the cabinet, chair, and bedstead makers.

The *yew-tree* was formerly cultivated for the manufacture of bows, but since the decline of the demand for it on this account, it has been much neglected. The wood is, however, valuable, though, like the two last kinds, not very abundant; it is hard and smooth, beautifully veined with red streaks, admits of a fine polish, and is almost incorruptible. It is employed by the turner and cabinet-maker, the millwright and the engraver. It may therefore be seen in tables, chairs, cups, spoons, toys, ornamental tea-caddies, urns, &c. Converted into axletrees, cogs for mill wheels, and floodgates for fish-ponds, it is found very proper and durable. By the engraver it is only used for large and coarse work.

Of all hard woods, that of the *holly* is the whitest, and is much used for inlaying, especially under thin plates of ivory. It is excellent for the use of the turner, and is highly prized by the millwright for the cogs of wheels; it also makes the best handles and stocks for tools, flails, the best riding rods and carters' whips, bowls, sheaves, and pins for blocks. Next to box, it is the most suitable wood for the use of the engraver. It is tougher, but not so hard as box.

Box is the only European wood which will sink in water. Its closeness of grain, hardness and toughness, are such, as

to render it admirably adapted to the purposes of the engraver on wood. The engraving is always made on the end of the wood, so that the fibres stand perpendicularly. When cut in this manner, the graver will make a clean stroke in every direction, and the piece is liable to warp but little. When cut plankwise, boxwood is extremely apt to warp, unless very well seasoned. No kind of wood turns smoother than this, and its yellow colour, when it is well polished, is very beautiful; it is much used for pulleys; for shuttles; for the bottoms of joiners' planes, especially their moulding planes; and, in short, is valuable for every purpose requiring wood which will bear friction well. When ivory would be too expensive, or cannot be obtained of the requisite dimensions, boxwood is commonly the substitute for it. Hence the consumption of it for combs, button-moulds, knife handles, and particularly for mathematical instruments, is very considerable. The bitter quality of boxwood secures it from the attacks of worms.

Ebony is an exceedingly hard and heavy kind of foreign wood, of a very smooth even grain, susceptible of a remarkably fine polish, and on that account used in mosaic and inlaid works, for toys, &c. It is of various colours, most usually black, brown, red, and green. The black is the kind most generally known, and preferred to that of other colours. The best is a jet black, free from veins and rind, very massive, astringent, and of an acrid pungent taste. Ebony is not in so much demand as formerly, from the improvements which have been made in giving other hard woods, especially the holly, a black colour. It is used for parallel rulers, and other mathematical instruments not requiring to be marked with figures, which the darkness of its colour would prevent from being distinctly seen. It is brought from Madagascar, the Mauritius, and the West Indies. The tree of the West India kind is seldom more than eighteen feet high, and the trunk five or six inches in diameter.

Lignum-vitæ is another foreign wood, firm, solid, ponderous, very resinous, of a blackish yellow colour in the middle, and a hot aromatic taste. It is a native of the West Indies, and the warmer parts of America. It is of considerable utility in the arts: by the sugar planters it is manufactured into wheels and cogs for sugar mills. The sheaves or pulleys in ship blocks are mostly made of this wood; which is also frequently formed into bowls, mortars, and various utensils. It is much used by the turner, making excellent castors, handles for tools, and other small ware; but as it is expensive, hard to work, and not very remarkable for its beauty, it is in little demand for the cabinet-maker.

Mahogany.

Mahogany is one of the most valuable woods imported into this country, and the tree, growing in full maturity, is one of the noblest productions of nature, attaining often the majestic height of one hundred feet. Mahogany balks are often three or four feet in diameter, and the diameter of one lately imported into Lancaster measured five feet. Mahogany varies very much in quality; that grown on rocks is the hardest, heaviest, closest in the grain, and most beautifully veined; and Jamaica wood is preferable to that obtained on the coast of Cuba and the Spanish Main, on account of its being mostly found on rocky eminences, while the latter is cut in swampy soils near the sea-coast, and is light, porous, pale coloured, and open grained. On soils neither rocky nor swampy, the wood is of a medium excellence. Hence a good idea of the value of a parcel of mahogany may be formed, if we know correctly the nature of the soil upon which it grew. Different parts, however, of the trunk of the same tree, vary somewhat in quality; and in felling the timber, the most beautiful portion of it is commonly left behind. The negro workmen raise a scaffolding of four or five feet elevation from the ground, and hack up the trunk, which they cut into balks. The part below, extending to the root, is not only of larger diameter, but of a closer texture than the other parts, most elegantly diversified with shades or clouds, or dotted like ermine with spots. This part is only to be come at by digging below the spur, to the depth of two or three feet, and cutting it through; an operation too laborious to be often attempted.—The remark just made, with respect to the superiority of the wood of the mahogany-tree, near the earth, is applicable to timber in general, and ought not to escape the observation of those who are desirous of selecting the choicest and most ornamental portions for particular purposes. The exquisite beauty of the finer kinds of mahogany, the incomparable lustre of which it is susceptible, exempt also from the depredations of worms,—hard, durable, warping and shrinking very little, it is pre-eminently calculated to suit the work of the cabinet-maker. Accordingly, these admirable properties, added to its abundance, and the largeness of its dimensions, have occasioned it to be manufactured into every description of furniture. From its being so little subject to shrink and warp, it is particularly excellent and much used for the patterns of iron and brass founders, especially for the patterns of wheel-work and other things which require the greatest nicety. It is the commoner sorts of mahogany which are generally wrought up in this way. The commoner kinds also are often stained black, and made to look to great advantage, for small turnery wares, such as picture frames.

The preceding catalogue of woods might easily be enlarged. but not, perhaps, with advantage. Several woods of home growth, which seldom come into consumption, and are alike, from their quality and their scarcity, of limited utility, as well as many of foreign production, such as dyewoods, which are rarely employed in the mechanic arts, we pass over as unnecessary in this enumeration. It will be more useful to subjoin a few remarks on the mode of seasoning and properties of timber in general. The goodness of timber not only depends on the soil and situation in which it stands, but likewise on the season in which it is felled. With respect to the latter point, considerable disagreement of opinion prevails; some are for having it felled as soon as its fruit is ripe, others in spring, and many in autumn. But as the sap and moisture of timber is certainly the cause that it perishes much sooner than it otherwise would do, it evidently seems to be a good general rule, that timber should be felled when there is the least sap in it, viz. from the time that the leaves begin to fall, till the trees begin to bud. The only plausible objection to a practice founded upon this idea, is, that the sap in winter is thicker than at any other season, and therefore may be of more difficult extraction, in the subsequent seasoning, than if the tree had been cut when it was more abundant and more fluid. In England, the work of felling timber usually commences about the end of April, because the bark then rises more freely; and where a quantity of oak timber is to be felled, the statute requires it to be done at that time, for the advantage of tanning.

The age at which timber is cut, is a matter of great importance; if cut too old or too young, it will not be so durable as when cut at a proper age. It is said, that oak should not be cut under sixty years old, nor above two hundred. It is easy to offer as a general rule, that timber trees should be cut in their prime, when almost fully grown, and before they begin to decay; but when it is inquired, how these particulars are to be determined, we are compelled to refer to judgment and experience as the only guides which can be depended on. Difference of soil, situation, and climate, hasten or retard the growth of timber so much, that the age at which any particular kind of tree arrives at maturity, cannot be correctly assigned. Marshall observes, that poplars may stand from thirty to fifty years; ash and elm-trees, from fifty to a hundred.

With respect to the best mode of seasoning timber after it has been sawed, a variety of opinions are entertained; but practical men, who seldom regard the notions of the speculatist, and who require a process not only effectual but convenient upon a large scale, consider no method better than that of

exposing the timber they intend to season, for a sufficient length of time to a free current of air, and every vicissitude of wind and weather. Boards from one to two inches in thickness, which have undergone this exposure twelve or eighteen months, they deem fit for use. They observe, that the mere drying of timber is not the same thing as seasoning it, and that unless it is frequently wet, while exposed, it receives little benefit. This is only stating, in other words, the necessity of extracting the sap. Some persons, however, advise the planks to be laid up in a dry airy place, out of the wind and sun, or at least free from the extremes of either; and that they may not decay, but dry evenly, they recommend them to be daubed over with cow-dung. They must not be piled on their ends, as in the common way, but one plank must be laid over another, small pieces of wood being interposed, to prevent the contact which would otherwise occasion an injurious mouldiness. This mode, though not so convenient, nor probably so effectual as the former, or common one, is certainly more rational than that recommended by others, of burying the timber in the earth.

To season timber in a short time, it may be laid in a pool, or running stream, in order to extract the sap, and afterwards dried in the sun or air. On a small scale, boiling water, as directed for beech, may be employed, by which the seasoning of green wood may be accomplished with the greatest expedition. The process will be found useful to turners and cabinet-makers. But whatever mode of seasoning be adopted, against shrinking, more or less, there is no remedy. The principal disadvantage occasioned by the shrinking of timber, is from the diminution of its transverse dimensions. When this kind of shrinking takes place in casks, for example, in any considerable degree, the hoops drop off, and these vessels fall to pieces; perhaps as great a number of them are destroyed by this cause as by any other. To obviate its effects, G. Smart has lately taken out a patent for constructing casks on a new principle: before he puts them together, he presses the wood into a smaller compass than it would ever be reduced to by drying: 32,000 vessels made according to this plan, have verified its utility in the most ample manner, not one of them having leaked, under circumstances that rendered those made in the common way useless.

The Venetians are supposed to be the first in modern times, who adopted the method of seasoning timber by charring it, which was done by exposing the piece to be seasoned to a strong fire, in the flame of which it was continually turned by an engine, till it was completely covered with a black coally crust, when it was taken out and fit for use. By this means, it became so hardened, as to resist the effects of earth, air, and

water, for centuries. The beams of the theatre at Herculaneum, were converted into charcoal by the lava which overflowed that city, and after a lapse of more than seventeen hundred years, the charcoal is as perfect as if it had been formed but yesterday. Casks charred in the inside are used to preserve water uncorrupted, and are particularly to be recommended for long voyages. Charring, also, is the best preparation which piles, or any kind of stakes, intended to be driven into the ground, can receive.

When boards or planks have been properly seasoned, without charring, additional care becomes necessary to preserve them against the depredations of worms, the effects of air, moisture, &c. For this purpose, Evelyn directs common sulphur to be put into a glass retort, with as much nitrous acid as will cover it to the depth of about two inches. The whole must be distilled to dryness, and rectified two or three times. The remaining sulphur is then to be exposed to the open air on a marble, or in a shallow glass vessel, where it will liquefy into a kind of oil, with which the timber must be rubbed over. This mixture, he asserts, will not only infallibly prevent the attacks of worms, but also preserve every kind of wood from decay, either in air or water. Two or three coats of linseed oil may also be used to defend timber from the influence of air or moisture; and some have recommended the wood-work of buildings to be painted, but this ought always to be deferred, till it is thoroughly dry.

If the wainscoting or other timber of a building be used too green, and has in consequence riven or cracked, it has been strongly recommended to cover it immediately with a solution of beef-suet, which will often close the crevices so effectually, that the defect will be scarcely perceptible. Some carpenters close the crevices with a composition of grease and fine saw-dust.

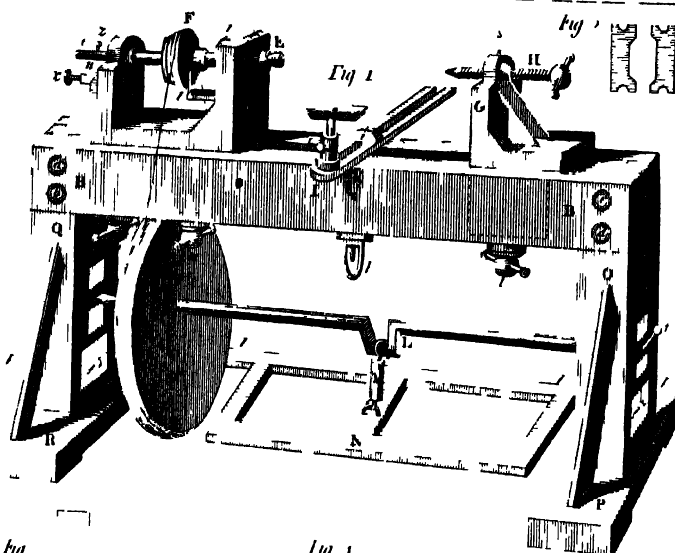
The timber employed in building, without due precaution, is extremely liable to destruction from the dry rot, which appears, by some late communications to the Society of Arts, &c. to be occasioned by a plant. It will destroy half-inch deal wainscoting in a year. The plant is of the creeping kind, and cannot rise above two inches; so that wood, in all cases, must be in contact with the earth to support it. To preserve wood, then, from its effects, it must be charred, painted, or prevented from touching the earth by bricks and mortar. It is never observed to commence in the middle of floors, so that it will probably be found sufficient to secure the ends of beams or joists. The plant has no adhesive powers but in contact with wood. Timber thoroughly impregnated with brine, or a solution of common salt, has been found by experiment to be secure from its destructive effects.

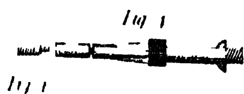
The experiments which have been made to ascertain the strength and quality of timber, under different circumstances, have been attended with results widely different from each other; but as it would be unsuitable to the plan of this work to enter upon the lengthened statements by which contradictory results are supported, we shall merely collect a few remarks, which seem to have obtained general assent. The wood next the bark of a tree, called the white, or alburnum, is much weaker than the rest. The wood of the north side of all trees which grow in Europe, is the weakest, and that of the south-east side is the strongest; this difference is most remarkable in hedge-row trees, and such as grow singly. The heart of a tree is never in its centre, but always nearer to the north side, and the annual coats of wood are thinner on that side. In conformity with this, it is a general opinion of carpenters, that timber is stronger whose annual plates are thicker. The trachea, or air-vessels, are weaker than the simple ligneous fibres. These air-vessels are the same in diameter and number of rows in trees of the same species, and they make the visible separation between the plates, or annual layers. Therefore the thicker these plates are, the greater the proportion they contain of the simple ligneous fibres, and the better the timber. A contrary opinion is nevertheless prevalent, and wood with a fine grain, or thin annual layers, is preferred. The tenacity of wood is greatest when it is green, and diminishes with drying. No person, perhaps, has made experiments on wood with so much minuteness as Buffon, who observes, that he invariably found the heaviest pieces to be the strongest, and he recommends an attention to this circumstance as the surest guide in the choice of timber.

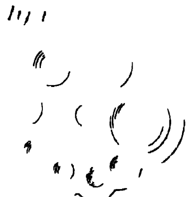
Banks is of opinion, that beams should be strong enough to bear twenty times the force they have to resist, or they will probably bend, and in time break. The same author also observes, that one piece of wood is much stronger than another, not only cut out of the same tree, but out of the same rod; or a piece of a given length, planed equally thick, and cut into several equal parts, these pieces will be broken with different weights. From a great number of experiments which he made on the strength of wood, he found that the worst or weakest piece of dry heart of oak, one inch square, and one foot long, bore six hundred and sixty pounds, though much bent, and two pounds more broke it. The strongest piece he tried of the same dimensions, broke with nine hundred and seventy-four pounds. The worst piece of deal, bore four hundred and sixty pounds, but broke with four pounds more; the best piece bore six hundred and ninety pounds, but broke with a little more.

The fibres of timber requiring so great a force to tear them asunder in a vertical direction, and being easily broken by a transverse strain, when compared to that of a rope carrying nearly an equal weight in all directions, opens a wide field for useful experiments. All timber trees have their annual circles or growths, which vary greatly according to the soil and exposure to the sun. The north-east side of the trees (being much smaller in the grain than the other parts, which are more exposed to the sun,) is strongest for any column that has a weight to support in a vertical direction; because its hard circles, or tubes, are nearer each other, and the area contains a greater quantity of them; nor are they so liable to be compressed by the weight, or to slide past each other, as when they are at a greater distance. On the other hand, this part of the tree is not fit for a transverse strain; because the nearer the hard circles are to each other, the easier the beam will break, there being so little space between them, that one forms a fulcrum to break the other upon; but that part of a tree, the tubes of which are at a greater distance, or of larger grain, is more elastic, and requires a greater force to break it; because the outside fibre on the convex side cannot snap till the next one is pressed upon it, which forms the fulcrum to break it on. It is generally observed in large timbers, such as masts, that the fracture is seldom on the convex, but usually on the concave side; which is owing to the fibres on the concave side being more readily forced past each other, and those on the convex side being so difficult to be torn asunder, that they cannot snap, in consequence of the largeness of the segment of the circle they describe when on the strain. The curve described by the inner layers of the wood being so large, and indeed little less than a straight line, cannot form a fulcrum to break the outer ones upon; and as the convex side, or that on which the fibres are extended, ought to be always free from any mortise or incision on the outside, the strength decreases as it approaches the centre.

In early periods, the trunks of trees were split with wedges into as many and as thin pieces as were required, in a manner similar to that used by lath-cleavers at the present day. The saw, though so convenient and beneficial, has not been able entirely to banish the practice of splitting timber used in building, or in making furniture and utensils. To be aware of the peculiar advantages of splitting timber, may be useful to artisans in wood generally. By its advantages, we do not so much allude to its being more expeditiously performed than sawing, as to the circumstance that split timber possesses greater strength and elasticity than that which has been sawn; for the fissure follows


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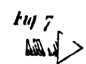











Fig 7

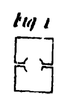
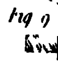
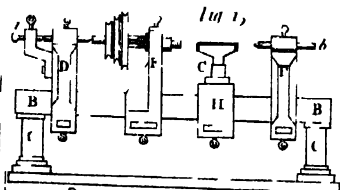
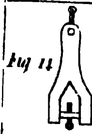
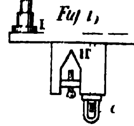


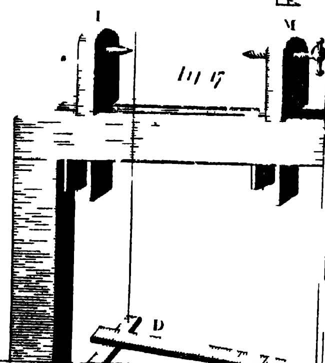

Fig 8

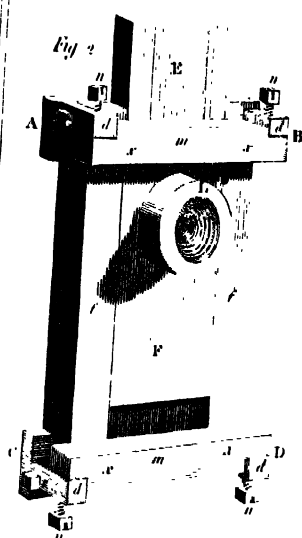

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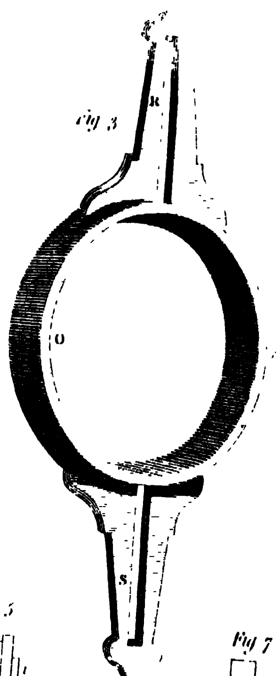

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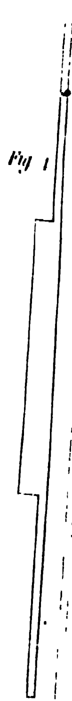


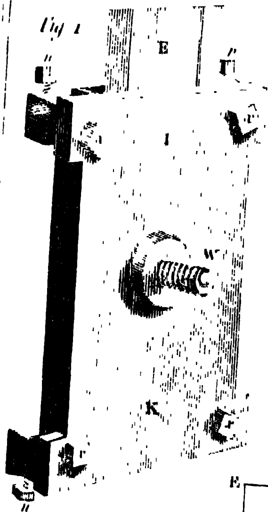

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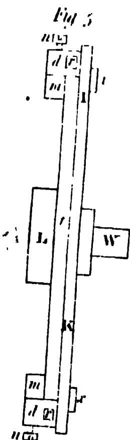

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Fig 2
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Fig 3
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Fig 1


Fig 4
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Fig 5
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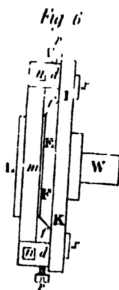
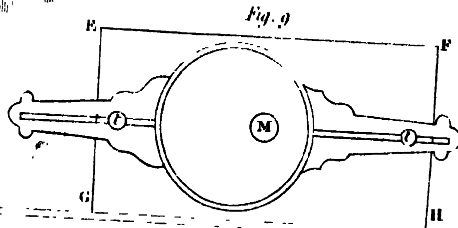
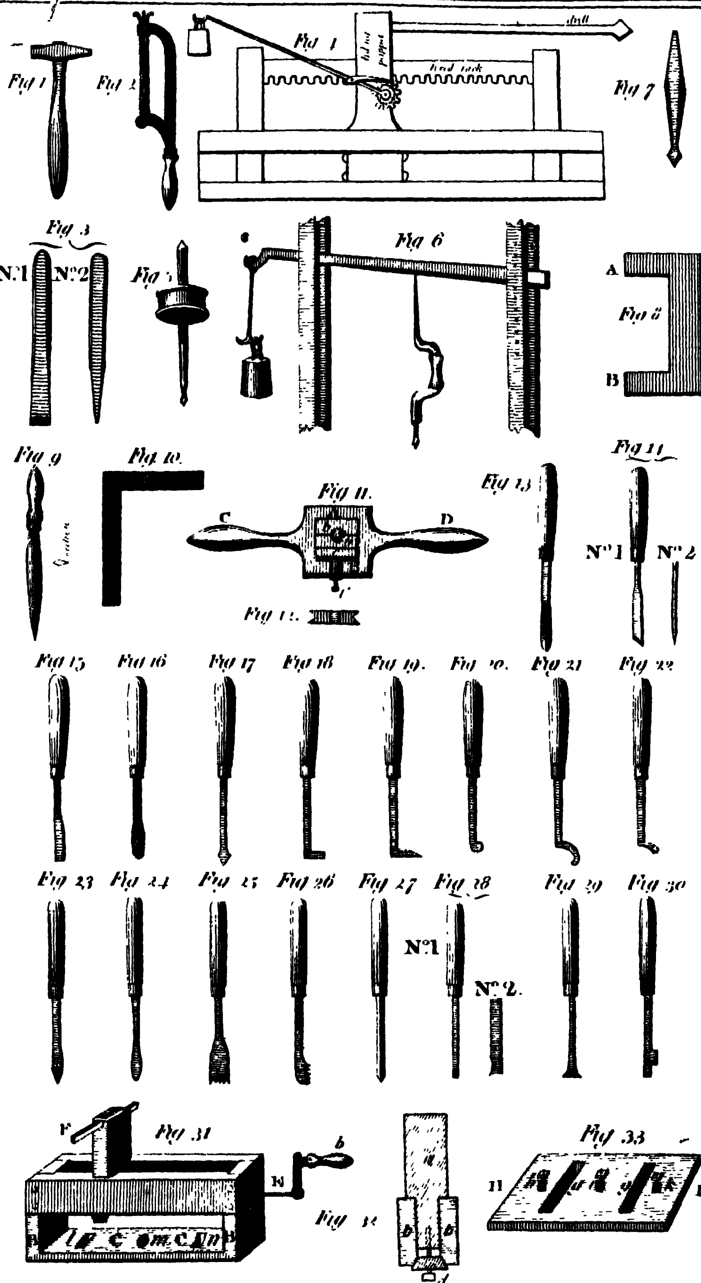
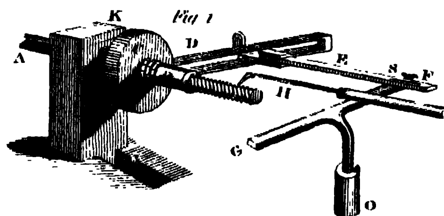

Fig 6
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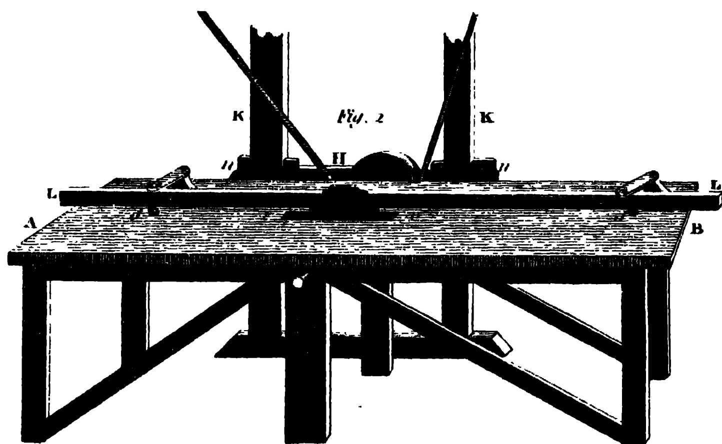

Fig 7
Fig 8
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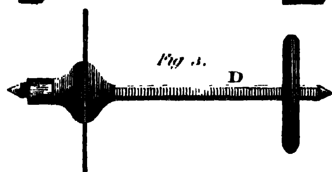

Fig. 9
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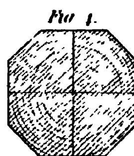


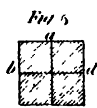
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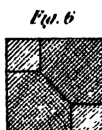


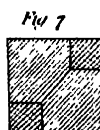


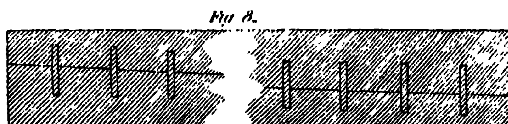












J. Smith del. Lukes sc.

Published by Henry Fisher, Caxton, London 18

the grain of the wood, and leaves it whole; whereas the saw, which proceeds in the line chalked out for it, divides the fibres, and therefore lessens its cohesion and solidity. Though split timber turns out often crooked or warped, this fault, which may sometimes be amended, is, on many occasions, not prejudicial. The fibres retaining their natural length and direction, thin boards, particularly, can be bent much better. This is a great advantage in making staves, or sieve frames, and in forming various articles of the like kind.

There is a curious point of difference between wood and metal, when employed as springs, which deserves to be noted, as it is not very generally known, though the information may occasionally prove very useful to the engineer. A metallic spring, if it has nothing to stop against, but is suffered to vibrate after performing the requisite action, will, in a short space of time, if the action be frequently repeated, either break or set. A wooden spring, when the vibration cannot be avoided, is the best substitute which can be employed, as, in the property alluded to, it is the reverse of a metallic one; if stopped in its vibrations, it soon sets or breaks; but if permitted to vibrate, its temper or elasticity suffers not the smallest diminution. The best wood for the purpose, is clean-grained deal, perfectly free from knots.

To measure round timber, let the mean circumference be found in feet and decimals of a foot: square it, multiply this square by the decimal, 0.79577, and the product by the length. Example: suppose the mean circumference of a tree be 10.3 feet, and the length 24 feet. Then 10.3 x 10.3 x 0.079577 x 24=202.615, the number of cubical feet in the tree. The foundation of this rule is, that when the circumference of a circle is 1, the area is 0.0795774715, and that the areas of circles are as the squares of their circumferences. But the common way used by artificers, for measuring round timber, differs widely from this in its result: they measure the girth, and reckon one-fourth of it equal to the side of a square, whose area is equal to the area of the section of the tree. They therefore square this estimate of one-fourth of the girth, and multiply the product by the length of the tree. According to this method, the tree of the last example would only exceed by a small remainder 159 cubical feet; for one-fourth of 10.3, or 2.575 x 2.575 x 24=159.135000.

In measuring hewn or square timber, the custom is to take the breadth in the middle, by placing two rules against the sides of the tree, and measuring the distance between them. In like manner they measure the breadth the other way, and if the two measurements are unequal, they are added together, and half their sum is taken for the true side of the square.

Of Saw-mills.

The sawing of timber is accomplished by manual labour and by machinery. Sawing by manual labour is so familiar to every one, as to require no particular description, in this place. With respect to sawing by machinery, the mills for the purpose are not numerous in Great Britain, nor does the utility of them appear to be so properly appreciated as in America, Norway, and other countries. A general description of the objects to be attained by the mechanism of a saw-mill on the largest scale, may be comprised in a few words: the saw is drawn up and down as long as is necessary, by a motion communicated (commonly by water) to the wheel; the piece of timber to be cut into boards is advanced by a uniform motion to receive the strokes of the saw; for here the wood is to meet the saw, and not the saw to follow the wood, therefore the motion of the wood and that of the saw ought immediately to depend the one on the other; and when the saw has cut through the whole length of the piece, the machine should stop and remain immoveable; lest, having no obstacle to surmount, the the force of the moving power should turn the wheel with too great rapidity, and break some part of the machine.

Circular saws, for ripping up boards or scantlings of moderate thickness, are not so generally used by artists, as would be found advantageous. We shall therefore particularly notice the construction of a circular saw-mill, invented by Smart, and used in his manufactory. Like his improvement in the art of turning cylinders, already described, it is distinguished by its simplicity and utility. A B, fig. 2, pl. IV. is a strong table, made of planks firmly braced together in the form of a joiner's bench. In the middle of this bench, a longitudinal opening, *r o*, admits the circular saw, F, which is made of well-tempered steel plate. G is a pulley on the same axis with the saw, and a rapid motion is communicated to it by means of an endless strap from a large fly wheel, turned by horse power. The saw is fixed on its spindle D, (fig. 3,) by a shoulder *d*, against which it is held by another moveable shoulder *e*, pressed against it by a nut, *k*, screwed on the end of the spindle, which is tapped for the purpose. The hole in the centre of the saw must fit the spindle exactly, and may be either square or circular. If it be circular, it must have a small notch in it, to fit a fillet on the spindle, that the saw and the spindle may revolve together. The ends of the spindle are turned off to cones, in the customary manner for working in centres. The cone or point nearest the saw, works in the end of a screw, *c*, fig. 2, screwed into the bench; the other point works in a

similar screw, screwed through a cross beam H, mortised between two vertical beams, KK, extending from the floor to the ceiling. The cross beam, H, can be raised or lowered in its mortises through the beams, KK, by wedges, *n n*, above its tenons, and two others below them. A long straight piece of wood, LL, called the guide, is connected with the bench by joints similar to those of a parallel ruler. It can be set at any distance from the saw, and fixed by screws passing through circular grooves, *d d*, cut through the bench. The front of the guide, LL, must be perpendicular to the plane of the bench; and it may then be made use of to set the plane of the saw also perpendicular to the same plane. In using the machine, the workman slides the end of the piece of wood to be cut against the saw as it turns round, and presses its edge against the guide, LL, at the same time, so that it may be cut straight.

When the saw is blunted by use, the centre screw, *c*, or that in the cross piece, H, must be turned back; the spindle and saw can then be removed; and by taking off the nut *k*, fig. 3, the saw will be loose, and another may be put on, or it may be sharpened, in the same manner as any other saw, while fixed in a vice. The teeth of the saw are set, that is, bent out of the plane of the saw, one tooth on one side, the next on the other, and so on alternately all round; the outsides of the teeth are not filed to leave a surface perpendicular to the plane of the saw, but inclined to it, and in the same direction that each tooth so filed is bent in the setting. By this means the saw, when cutting, first takes away the wood at the two sides of the kerf, or passage which it makes, leaving an angular ridge in the middle of it, the use of which is to keep the saw steady in a right line, that it may not have so much tendency to get out of the straight, in any place where the wood is harder on one side than on the other.

On giving a curved form to Wood.

Curved wood is frequently purchased by millwrights at a very high price; and such is its scarcity, that very imperfect pieces are frequently made use of, not only from motives of economy in the first cost, but from necessity. The inequalities also of wood which is naturally curved, are often so considerable as materially to impede the workmen; but when it is intended to curve it artificially, it may be dressed in its straight state, so as to require very little labour afterwards. The following observations, therefore, on the curving of wood, from a Treatise on Carpentry, by J. H. Hassenfratz, will be interesting to many, and will develope some principles with

respect to the management of wood, which are not very generally known.

When trees are young and tender, their stems may be bent either by cords, or by poles, stakes, or frames. They are kept in this situation so long that they retain the curvature intended to be given them, even when disengaged from the obstacles by which they are held.

Of all the methods of bending trees, that applied to young and growing wood is the most easy and convenient; their suppleness and their elasticity admit of their assuming any form that is desired. There are few, to which, with proper care, the most singular forms may not be given; but, it is true, they are often reduced to a state of constraint and disease prejudicial to their growth.

The curving of wood after it has been cut, though more difficult, is, however, more customary, because such pieces may be selected as are best adapted to the objects for which they are intended, and a suitable curvature may be given them immediately.

The process generally employed, is founded on the property possessed by caloric, of augmenting the elasticity of wood by penetrating it, and of diminishing its elasticity when it retires.

Accordingly, to give a curvature to thin pieces of wood, such as pipe staves, and the planks that cover the sides of boats, they are heated in the part where the curve is required, and they are gradually bent as they become hot.

But caloric, applied to a particular portion of the wood, while the other is in contact with the air, heats it unequally, and only partially increases its elasticity: in curving, some parts become stiff, and others bend, which produces an inequality of curvature, and sometimes cracks in the interior, and splinters on the surface of the wood. The only method of correcting this inequality, is to heat the wood alike in every part.

Ovens and stoves, gradually heated, facilitate the curvature of wood, by procuring an equal heat; but the risk of injuring the wood in a dry heat is very considerable. The elasticity of wood, also, is in proportion not only to its temperature, but likewise its humidity. At an equal temperature, the same pieces of wood have different degrees of elasticity, according to the quantity of water by which they are impregnated; in the same manner as, with an equal degree of humidity, they are the more elastic the more they are heated.

We have an example of the two-fold influence of humidity and of caloric, in putting together two pieces of wood, as the tenon and mortise, in which the mortise is only one-third of

the size of the piece that is to go into it. This manner of joining, apparently so extraordinary, is considered such an important invention, that most of those by whom it is practised keep the method a secret. It was the process employed in producing this effect, that suggested the method now employed for curving with facility the thickest and most obstinate pieces of timber; the whole art consists in impregnating the pieces of wood with humidity, by procuring them a uniform temperature, then to bend them, and suffer them to cool, in the form they are intended to assume.

To heat and to impart humidity to wood, three different processes are employed; the first is by boiling water, the second by steam, and the third by wet heated sand.

The boiling of the wood in water, is attended with the inconvenience of dissolving part of the substance of the wood; at least, on drying again, it shrinks both in thickness and in length; its strength and elasticity are considerably diminished. The next method tried was the vapour stove, which was a chest proportioned in size to the wood to be curved, formed of thick planks, firmly joined together. The wood intended to be submitted to the action of the vapour, is placed upon supports. For small chests, a boiler may be placed at one of the extremities, the wood being introduced by a door at the other. In large chests, the boiler is placed in the middle, and the wood is introduced at both ends. The boilers communicate in the interior of the chest by means of a pipe. The vapour formed by the ebullition of the water, impregnates the wood with humidity, augments its elasticity, and renders it fit to be curved. Vapour stoves require little care or expense; but they can only be used for planks of a certain thickness, because they cannot impart to wood a higher temperature than that of boiling water, which is insufficient to give thick pieces the elasticity they require in order to be curved.

These considerations led to the invention of the sand stove, which is formed of four walls of stone or brick, having in the middle two fire-places that communicate with several circular flues to convey the caloric, the heated air, and smoke, to the two chimnies at each end. Over these flues are plates of metal, forming the bottom of the chest in which the sand is put. The flame and the smoke circulating in the flues, heat the plates, which communicate heat to the sand. This stove is an imitation of the sand baths, which have been immemorially employed in a great number of chemical operations, and in various manufactories, for affording an equal heat.

As sand is capable of being heated to a much higher tem-

perature than boiling water, the wood placed in this kind of stove may be subjected to a much more powerful heat; but if there was nothing in the stove but the sand and the wood, the heat might disengage from the latter, the gaseous substances which compose it, and convert it into charcoal. To prevent this, one or two boilers, filled with water, are placed in the middle of the stove. The steam created by their ebullition impregnates the sand with humidity, which likewise penetrates the wood, and the heat evaporates only the water which is continually supplied by that which is disengaged; by these means, the constituent parts of the wood are preserved.

It may be supposed that in this operation, some portion of the component parts of the wood are evaporated, and that it is consequently liable to a commencement of deterioration: but if care be taken to remove it as soon as it is sufficiently hot and humid, the injury is imperceptible.

The sand stove is covered throughout its whole length, to impede evaporation and the loss of heat.

The wood is introduced lengthways into the stove, at the two ends, and being placed on gratings fixed for the purpose, it is covered with sand.

When the wood has been rendered sufficiently hot and humid, it must be bent upon a surface making the desired curve. The force which produces the curvature may act by means of cords, pulleys, and even capstans. The piece having assumed the desired form, it must be left, with the force still acting upon it, to cool and dry.

When the piece of wood is not thick, the pressure of men, or even of weights, will frequently afford sufficient force to produce the necessary curvature.

Advantageous Method of converting the Trunks of Trees into square Timber.

The method we are about to describe, of converting all timber that is straight, and intended for square beams, to great advantage in general use, is included in Smart's patent for hollow masts; but the ingenious patentee, as far as relates to lessening the consumption of English oak, and introducing the larch and firs of our own growth into general use, has liberally granted licences to all who choose to apply to him for them, with some trifling exceptions with respect to masts, yards, bowsprits, &c.

Fig 4, is a section of the but-end of a tree, two feet in diameter, sawn or chopped diagonally. Fig. 5, is the other end, sawn square, one foot each side: cut it exactly through

the centre in two cross-cuts, *a b, d e;* it will produce four pieces, which are put together, as in fig. 6 and 7, with the centre turned outwards, the but-end of one piece with the small end of the other, and dowel and bolt them together as in fig. 8. A beam will then be formed, whose section is shewn in fig. 6 and 7, regular from one end to the other, with the advantage of having the heart of the tree in the place where the hardness and strength are most wanted, viz. in the corners, which form the abutments; whereas the same tree squared into a parallel beam, would have been much smaller, and the soft or sappy parts of the wood exposed to the action of the air and moisture. In flush framing, it is observable, that the failure of all timber in old buildings has commenced much sooner than it otherwise would have done, owing to the sappy wood being at the corners of the principal beams. This sappy wood soon decays, as its spongy quality attracts the moisture; whereas the heart, especially of oak, will be as sound as the first day it was used.

As beams, taking their weight horizontally or on any transverse bearing, have their principal strain on the upper and lower surface, every workman ought to guard against having sap in beams, because if they do not immediately decay, they shrink, so as to loosen all the framing, and soon cripple the building or machine; but on the above plan, the sappy or worst part of the wood is excluded from what would cause its decay, and the timber increased in quantity so as considerably to overbalance the extra labour and expense. A tree of oak, forty feet long, two feet in diameter at the but-end, and one foot at the top, when put together on this plan, will have its sides each eighteen inches square, and will contain ninety feet; whereas on the old plan, forty feet would be the contents of a square beam cut from the same tree; fifty cubic feet would have been cut off as slabs, or chopped up for the fire. Estimating the expense of thus putting together a beam, of the dimensions in question, to cost £3, (and it would probably not amount to more where the price of labour is highest,) and the fifty feet saved to be worth no more than £6; the proprietor would save £3 by each beam so converted. The dowels ought not to go through, as that would weaken the timber. In an eighteen-inch beam, the dowels should come within three inches of the outside; but where a mortise is cut in place of a dowel, it is proper to have an iron screw bolt to prevent the joint opening with the pressure of the tenon; and the work ought to be put together with screw clamps, for nails or hammers bruise the wood, and weaken or destroy the cohesion of its fibres for a considerable depth.

Of the Tools used in the working of Wood.

We do not here intend to speak of the tools used in turning wood, they having been already noticed. We allude more particularly to the tools required by the carpenter, joiner, and cabinet-maker, and which differ not from each other so much in their general construction and name, as in size, and the varieties necessary for coarse and large, or ornamental and small work. We offer the enumeration of the tools used by these artisans, not with the hope that the mere enumeration will convey any information of importance, but to afford an opportunity of making a few remarks on the mode of using and choice of them, and on those peculiarities in their form, upon which their excellence chiefly depends.

The principal tools employed in the working of wood, are, the axe, the adze, various sorts and sizes of saws, planes, chisels, hammers, and boring tools.

The construction of the *axe* and the *adze*, and their use in chopping or hewing, scarcely require any remark. In grinding these tools for use, the general rule observed in grinding all other edge-tools must be attended to, viz. that of suiting their edge to the work for which they are intended. When the wood they are to cut is hard and knotty, the part ground off to form the edge must be short, so as to leave the tool rather thick and strong near the edge; on the contrary, for soft, clean-grained stuff, the part alluded to may be brought to an acute angle, so as to form a thin wedge. A workman applied his axe to the chopping of bones, and thought the metal it was made of very bad, or badly tempered, because it became notched or gapped, almost at every stroke, till the edge was gone. The fact was, that it was ground to so acute an angle as only to be fit for cutting fir. Such mistakes, however gross, are not uncommon. The tool in question should have been ground so as to have had an edge almost like that of the chisel for chipping iron. The axe is ground on both sides to form the edge: the adze is a much thinner and lighter tool than the axe, it is ground only on one side, namely, the inner; the part ground is at a right angle to the handle; and the blade is arched to the portion of a circle, the radius of which is somewhat less than the length of the handle. The adze is much used by the cooper, as well as the carpenter and jôiner; it will pare away very thin slices or chips, and leave a much smoother surface than the axe, which, besides, cannot, like it, be applied to a surface in a horizontal position. That part of an axe, adze, or any other tool, which is ground off to form the edge, is called the *basil*.

Of Saws.

Saws are made of plates of steel; if they possess great elasticity, and bend equally in a bow, they are judged to be well tempered, and evenly ground. The edge in which the teeth are cut, is thicker than the back, that the back may readily follow the edge. The teeth are cut and sharpened with a triangular file, the blade of the saw being first fixed in a whetting block or vice. After the teeth have been filed, they are set, that is, turned out of the right line, that they may make the kerf or fissure wider than the thickness of the saw-plate, and thus prevent the friction which would otherwise impede the motion of the tool. If the first tooth be bent to the left, then the next is turned to the right, and so on; and it may also be remarked, that the extremity of each tooth, at the outside corner, is left higher than on the inside corner, which tends to facilitate the cutting. Hence it will be observed, that the teeth of Smart's circular saw, which have been particularly noticed, are formed in the same way as those of the common saw, and for the same reasons, in addition to those stated on page 99.

The instrument with which the teeth of saws are bent, is usually a piece of iron or steel, five or six inches long, with several nicks in the edge, at right angles to its length, and of different sizes. The tooth intended to be bent, being slipt into the nick which it will exactly fill, and the saw in the mean time being held fast, the effect of bending the tooth may readily be produced by twisting the instrument up or down. The teeth of a saw are made larger for coarse cheap stuff, than for hard and fine, in cutting which large teeth would make too great a resistance. The plate of a saw should be quite straight, or it cannot be depended upon for making a straight kerf.

In large towns, there are men who earn a portion of their livelihood by sharpening saws, and those who perform the business well, receive considerable praise for their ingenuity, from journeymen, not always of the most clumsy and idle class, who employ them without reflecting that the skill they admire is easily attained by a little attention; that the time employed in carrying, looking after, and fetching their tools, is generally equal to what would be required for repairing them at home; and that they can therefore seldom call themselves gainers, even if they had nothing to pay for the work they have had done, or if it were no inconvenience to be for a time deprived of a tool almost constantly required to be at hand. The teeth of saws have a proper degree of acuteness, when comprising an angle of about sixty degrees. In sharpening them, the

whole of the outer arris of each tooth, should be made sharp; this can only be done by moving the file in a straight direction, which will make the slanting sides of the teeth flat. Saws used for dividing wood longitudinally, or in the direction of its fibres, may have the front edge or apex of each tooth standing almost as forward as the base of the tooth on that side next the lower end of the plate. But this form, in transverse or cross-cutting, would be inconvenient, as it would hinder the workman from pushing forward the saw; tenon-saws are therefore usually made so that the apex of the tooth is not more forward than the centre of its base.

The saws in most common use are the following, viz. the *pit-saw*, which is a large two-handed saw, for sawing timber in pits, chiefly used by the sawyers.

The *whip-saw*, which is also two-handed, is used in sawing such large pieces of timber as the hand-saw will not easily reach.

The *hand-saw*, which is made for a single man's use; the length of the plate is about twenty-six inches, and it is generally made with about four teeth in an inch. It is used in cutting wood across, as well as in the direction of its fibres. The teeth toward the lower end of it are rather smaller than those at the upper end, or broadest part of the plate, which facilitates the working of the saw in that part of its course, when the workman has the least power upon it, and the wood, on the surface and at the sides of the kerf, particularly in cross-cutting, are not so much torn as they would be if the teeth were all of equal size.

The plate of the *pannel-saw* is about the same length as that of the hand saw, but it contains about half as many more teeth in the same compass. It is used for cutting very thin boards in any direction which may be required.

The *bow* or *frame-saw* is furnished with cheeks; by the twisted cords from the upper parts of these cheeks, and the tongue in the middle of them, the upper ends are drawn closer together, and the lower set further apart; so as to tighten the plate, which is too long and narrow to be kept straight without a frame.

The *tenon-saw* is used for cutting across the fibres of wood, and derives its name from its use in forming the shoulders of tenons. The smallest saw to which this name is given, is about fourteen inches, and the largest about twenty inches long. The number of teeth in an inch are from eight to ten, according to the length of the plate, the larger sizes of which have the fewest teeth in the same compass.

The saw used in cutting the tenons of sashes, is called a *sash-saw;* the plate is about eleven inches in length, and the number of teeth in the inch about fourteen.

The *dove-tail-saw* is used by joiners and cabinet-makers in dove-tailing drawers, &c.; the plate is about nine inches long, and the number of teeth in the inch about fifteen.—The plates of the tenon-saw, the sash-saw, and the dove-tail-saw, are so thin, that the back of them is let into a stout piece of iron or brass, to keep them from bending, and as they are not intended to cut into wood their whole breadth, this addition is no disadvantage.

The *compass-saw* is used for cutting a circular or any other compass kerf: its formation is peculiar; the teeth are not set, as the setting of a saw has a tendency to keep it in a right line; the teeth are small, about five in an inch; the plate narrow, about an inch in the broadest part, and gradually diminishing to about a quarter of an inch at the lower end; the cutting edge is thick, and the back very thin, so that it may have a compass to turn in. The sides of this saw should either be correctly flat, or a little concave like a razor, otherwise it will not work well.

A small kind of compass-saw, called a *key-hole-saw,* is used for quick curves, such as key-holes. The handle is long, and in shape similar to that of a chisel, but perforated through its whole length, in order that the saw, which is fixed by a screw, may be set at any distance within the handle. Hence in cutting the smallest curves to which it can be applied, or at the commencement of the work, or when it is only wanted to saw through an inconsiderable depth, but a small portion of the saw is allowed to project from the handle; by which means the springing or unsteadiness of sawing with the end of a long narrow blade is avoided, and more force can be applied, without the hazard of breaking the plate.

Of Planes.

Planes of different kinds form a very important part of the tools of artizans in wood. A few remarks in explanation of technical terms, will enable us subsequently to be more concise and intelligible in noticing this class of tools. The block of wood in which the blade or chisel of a plane is fixed, is called the stock; it is mostly made of beech or some other hard wood, exceedingly well seasoned. The blade or chisel is called the iron; it is composed of iron and steel welded together, the fore part of the lower half of it, when in the stock, containing the steel. The under-side of the stock is called the sole. The height or depth of a plane are synonymous terms, signify-

ing the dimension from the sole to the upper surface. The handle of a plane is called the tote. That part of the aperture in the stock upon which the iron is laid and secured by the wedge, is called the bed, which is a plane surface, making a different angle with a line perpendicular to the sole, according to the use for which the plane is intended. For the jack-plane, the trying and the smoothing-planes, the angle of the bed is usually from forty-two to forty-five degrees; for moulding planes about thirty-five, and for those planes which operate by scraping, it is almost perpendicular, not making an angle of more than five or six degrees. The angle which the iron makes with the perpendicular alluded to, is called its pitch, and the greater this angle, the lower is said to be the pitch of the iron. The basil of the iron forms an acute angle with the steel side, which is not ground, but always kept level. In grinding and whetting plane irons, the basil must be made as flat as possible, or in a small degree concave, otherwise it will not seem to be sharp when in use.

Planes are generally about three inches and one-eighth deep; the jack-plane is sometimes rather more, and the smoothing-plane is mostly rather less. The blades of planes are, in many cases, made double, a simple expedient of remarkable utility in planing cross-grained stuff. The addition made to the blade for this purpose, consists of a piece of iron of the same breadth as the blade, with its lower end very thin, and of the same shape at the edge as the edge of the blade. This piece of iron, usually called the top-iron, is connected by a screw with the blade, at any necessary distance from the edge of which it can be fixed. The top-iron, the edge of which should never extend below the sole, is fastened upon the front or steel side of the blade, and the space between its edge and that of the blade, determines the thickness of the shaving. It is always necessary to make the top-iron fit the blade so correctly that no shaving can get between them; for this end, it is arched a little towards the lower end, and the concave side of this arch being turned inwards, the screw necessarily makes the edge fit closely the level surface of the blade. The top-iron is generally employed in the jack-plane, and almost always to the trying-plane, the long-plane, and the jointer. To the smoothing-plane, and the various sorts of moulding-planes, it is not used.

If the iron of a plane project too far, the blow of a hammer, on the fore end of the stock, will slacken the wedge and raise it in a small degree. In this case, the wedge must be refastened by driving it down with a light blow or two before the plane is used again. A smart blow on the fore end of a

plane will loosen the wedge so much that the iron may easily be withdrawn by the hand. Instead of striking the fore end, for these purposes, some workmen strike the upper surface of the stock, near the orifice for the shavings.

The *jack-plane* used by joiners, is generally about seventeen inches in length. Its use is to take off the greater irregularities of the stuff, left by the axe, the adze, or the saw, and it is therefore the first plane employed. To suit the coarseness of its work, the cutting edge of the iron rises with an arch of considerable convexity in the middle, and the opening or mouth which admits the shavings through the stock, is wider at the sole than that of any other plane. The iron is often used without a cover; the quantity of its projection must be regulated by the texture of the stuff, in proportion to the hardness or knottiness of which it must be lessened; the due degree of it is easily ascertained by trial: it must be adjusted so as not, on one hand, to require hard pressing down, or many strokes to be made in reducing the wood; nor, on the other, to fatigue the workman and tear the stuff, by taking hold too keenly. The convexity of the cutting edge of the iron, prevents the corners from entering the wood, which ought never to occur, as the effect would be to spoil the work and impede the progress of the artisan.

When a piece of stuff has been nearly reduced to the intended form by the jack-plane, the *trying-plane* is made use of to produce a higher degree of regularity and smoothness. It is four or five inches longer than the jack-plane, and its iron is broader, set with a less projection, not so convex on the edge, and, like the two following sorts of planes, always used double. This plane, in taking off a shaving, is pushed along the whole length of the stuff, whereas the strokes given with the jack-plane are only within arms' length.

The third plane made use of in facing a piece of stuff with the utmost exactness, is the *long-plane*, which is four or five inches longer than the trying-plane, and proportionately broader, while the projection and convexity of the iron are somewhat less.

The *jointer* is the longest plane of all; its edge is very fine, and scarcely stands out above a hair's breadth; it is chiefly used for shooting the edges of boards perfectly straight, so that when joined together their surfaces will exactly coincide, and the juncture be hardly discernible. The jointer is made about thirty inches long.

As the last-mentioned plane, from its extraordinary dimensions, would be unhandy in shooting short blocks, a short kind of jointer, called the *strike-block*, is also in common use.*

It is much employed in planing the ends of boards, across the fibres, and the inclined plane forming the bed, is lower than that of the jointer. When employed for soft wood, the angle is only increased two or three degrees; but for fine cabinet work, when the stuff is hard, it is often considerably more, so as to make an angle with the perpendicular of fifty-five or even sixty degrees. In the latter case, the position of the basil is reversed, so as to be in front, or next the fore end of the stock. The usual length of the strike-block is eleven or twelve inches.

The *smoothing-plane* is about seven inches in length, it has no tote or handle, and otherwise differs in shape from any of the planes yet mentioned. The sides of the stock are convex, and its whole figure resembles that of a coffin. The inclination of the bed is similar to that of the jointer, which it also resembles in the set of the iron. It is the last plane used in finishing off the surface of wood, and from its smallness can easily be applied to smooth any small part which the large planes cannot touch; and the direction in which it is wrought can also be varied with facility, so as to suit cross-grained stuff. To secure these advantages more effectually, it is wrought, like the jack-plane, with short strokes. From this description of its use, it will be obvious, that though it is used in finishing off wood, it is *smoothness*, and not *straightness* of surface, which it is calculated to produce. But if the work be well managed, the inequalities which it leaves are not perceptible to the eye, and are therefore left with impunity in tables, bureaus, desks, and other furniture, even of the best kinds.

Though the double iron is an excellent invention, and the use of it is, in fact, the best general remedy known against the curling or cross-grained stuff of ordinary quality; yet, without some other assistance, the planing of many of the finest specimens of mahogany, and many other woods, among which fustic may be particularly mentioned, would be to the last degree a difficult and perplexing operation to the workman. Hence a plane, the stock of which is usually made of the shape and size of the smoothing-plane, is fitted up so as to act by scratching or scraping. The blade, or iron, on the steel side of it, is covered with rakes or small grooves close to each other, and all of them in the direction of its length: when therefore it is ground, and the basil formed, its edge presents a series of teeth like those of a fine saw; the bed of the stock intended to receive it is inclined only about six degrees, and consequently when the iron is fixed it is almost perpendicular. On account of these teeth in the iron, the plane obtains the name of the *tooth-plane*. With this kind of a plane, however hard the stuff may be, or however cross and twisted

its grain, the surface may be made every-where alike, and will not be rougher than if it had been rubbed with a piece of new fish-skin. This roughness may be effectually removed with the scraper, which is a thin plate of steel, like part of a common case-knife, the back of it being let into a piece of wood, as a handle.

To form the concave or convex surfaces of the rims of carriage-wheels, or the top rails of a camp-bedstead, and work of a similar nature, the sole of the plane must be curved in the same degree as the concavity or convexity to be produced. Planes of this description are called *compass-planes;* they resemble the smoothing-plane in size, and also in shape, excepting so far as regards the curve of the sole. A plane of the size and shape in question, with a concave sole, is also distinguished by the name of a *forkstaff-plane;* and one which is convex, is sometimes called a *round-sole.*

The *rabbet* or *rebating plane,* is employed in taking away (by shavings) from the edge of a board, a piece in the form of a square or rectangular prism, so as to leave a groove consisting of two surfaces at right angles to each other. This mode of reducing the stuff is required for some cornices, and various sorts of ornamental work. The groove formed by the rebating-plane, is also employed to receive the edge of another board cut in a similar manner, so that the two lap over each other to the breadth of the rebate, and form one even surface. Rebating-planes deliver their shavings at the side, and not at the top, like the planes hitherto described. They are also of various kinds; some of them are provided with a fence which regulates the horizontal breadth, and others with a stop, which determines the vertical extent or depth of the rebate; while some have both stop and fence, and others neither. Rebating-planes without a fence have the iron the whole breadth of the sole; some of them have the cutting edge of the iron only on the side, and others only on the bottom of the stock; these are employed for dressing and finishing with exactness, separately, either side of the rebate.

The plane by which a square groove is taken out of the edge of a board, so as to leave a ridge on each side, is called a *plough,* and the operation of cutting with it is called ploughing. To prevent the necessity of having, for grooves of different sizes, a great number of ploughs, which would be cumbersome and expensive, a tool of this description, called a universal plough, is manufactured. The stop and fence of the universal plough are moveable, and it admits alternately, according to the extent of the groove desired, ten or a dozen different sizes of irons.

Moulding-planes admit of the greatest diversity of contour, which is necessarily the reverse of the moulding produced. The figure of the edge of the iron and that of the sole, should exactly correspond; in whetting the iron, great care must be taken not to injure its form: the whole of the sole, or at least the ridges of the moulding, especially if narrow at the base, should be made of box-wood, which unites, in a greater degree than perhaps any other wood, the valuable properties of hardness, toughness, smoothness, and durability.

Of Chisels.

The very large chisels used by carpenters, millwrights, and others, for heavy coarse work, are generally composed of iron and steel, welded together,—the steel forming but a small portion of the whole mass of metal, as it seldom extends higher than the broad part of the tool, and often constitutes no more than a third of the thickness. The small and middle-sized chisels of the best kind, are always made of cast steel. As all chisels, not exclusively employed in turning, are driven more or less by percussive force, they are (except the socket chisel) provided with a shoulder, which abuts against the ena of the handle into which the tang is driven, and prevents it from being split by blows. The basil of chisels is on one side, and if well formed should be quite flat.

The *gouge* used by the joiners and cabinet-makers is similar to that of the turner, though not always sharpened in the same way. The edge is generally, by joiners and cabinet-makers, for small work, made straight across the end, and not convex like the turner's gouge. The millwrights, again, often make the basil on the hollow or concave side of the gouge, in order to cut with it perpendicularly.

The thin broad chisel, the sides of which are parallel for a certain length, and which afterwards becomes narrower towards the shoulder, obtains the name of the *firmer chisel* when driven by the mallet, and of the *paring chisel*, when the hand only is employed in cutting with it.

The common *mortise chisel*, the section of which is a rectangle approaching almost to a square, is, as its name implies, employed in making mortises; the basil is made on one side of its narrow sides. It is, from its form, very strong, which is necessary, not only on account of its having to sustain extremely heavy blows with the mallet, but because it is partly used as a lever to get out the pieces of wood as they are severed, in the course of cutting the mortise.

The *socket-chisel* is distinguished from other chisels by its having a conical socket, instead of a tang and shoulder, to receive the handle. It is used for the same purposes as the mortise-chisel, but is not so thick in proportion to its breadth It is much used for very large work.

The upper end of the handles of chisels which are driven by percussion, should be made convex, as they will then be least liable to be split or injured by blows.

Boring Tools.

The largest of the boring tools for wood, is the *auger*. The oldest construction of the auger, which is yet in common use, in various parts of the country, cannot be wrought till a small excavation has been made, which is mostly done with a gouge, at the place where the hole is to be; and till the auger arrives at a considerable depth, the motion of it is very unsteady. This old auger is shaped like a gimblet, except at the point, which is like that of a nose-bit. An improved construction of the auger, by Phineas Cooke, appeared to possess so much merit, that the Society for the Encouragment of Arts presented thirty guineas to the inventor. This is called the spiral auger, for it consisted of a rectangular bar of steel, twisted in the shape of a bottle-screw, terminating in a short taper screw, with a double worm like a gimblet. The upper part, like that of the common auger, is formed into a large ring, in which the handle is inserted, at right angles to the length of the auger. That part of the screw adjoining the spiral, presents an edge which cuts the wood. This auger is not very commonly used, but it pierces the wood much truer than the common one; no picking is necessary before it can be wrought, nor does it require to be drawn out to discharge the chip. It is, however, better adapted to the boring of soft wood than hard. Its use being on this account more limited than workmen like, besides its being not cheap in its first purchase, and if not made of good metal and very carefully tempered, easily changing its form, it will probably not regain the character it once acquired. The latest construction of the auger has been found to answer so well, that it will probably, ere long, nearly supersede the use of the spiral and common auger. Like the spiral one it terminates with a gimblet-screw, which draws it down into the wood, while the workman turns it round and presses upon it; and another peculiar advantage of which is, that its point can be set precisely upon the centre marked for the perforation, the proper direction of which there is then a good chance of preserving, while the broad-ended auger is apt to deviate considerably at its very commencement. Immediately above

the spiral screw, it is, for a short length, rather of a prismoidal shape, tapering a little upwards, like the socket chisel below the conical part. The prismoidal part has one cutting edge which cuts the sides of the hole, and another which cuts the bottom. The core rises as the act of boring goes on, in the form of a spiral shaving. Above the prismoidal part, the shaft may be of any shape at pleasure, that possesses sufficient strength, taking the obvious precaution of making its diameter less than that of the bore. The general disadvantage of augers with gimblet points, is, that when they encounter knots or hard places in the wood, they are apt to break.

Every one who makes use of an auger in the usual way by hand, knows by experience that he never can so completely exert his strength in this operation, as when he bores down perpendicularly, with his body leaning over his work; and it is very evident that by every degree of the auger's elevation from this situation, his power is of less effect, consequently his labour is increased, and his work so much retarded, that in the former position he can bore four holes for one in the latter. In hand boring, also, the unsteady and irregular motion of the auger, (particularly when the common old-shaped one is used,) at its first entrance into the wood, occasions the holes to be bored very crooked, often larger without than within, and very wide of the direction aimed at, especially if the wood proves hard and knotty, and the holes are deep. Regarding the prevention of these disadvantages as a matter of considerable consequence to ship-builders, and a variety of other artists, the Society for the Encouragement of Arts, &c. presented the sum of fifty pounds to William Bailey, for his invention of a machine for boring auger-holes, by the use of which the force of the workman, and consequently the dispatch of his operations, are equally exerted in all directions. It is unavoidable also, in the usual way of boring, for the action of the auger to be discontinued twice in every revolution; but with the machine the motion is continued with equal force and velocity, till the auger has bored to the depth required. A description of this machine, illustrated by a plate, may be seen in Bailey's Advancement of Arts; our limits will not allow us the further notice of it here, but the fact of such a contrivance having been executed, being mentioned, the ingenious mechanic will not perhaps find it very difficult to contrive one for himself.

The contrivance for boring next entitled to notice, is the *stock*, which is in effect a crank, not unlike the hand-drill, and frequently made of iron, though generally of wood, defended by brass, at the parts most subject to wear. Where the crank terminates two short limbs project from it, in a line with each

other, and parallel with that part of it by which it is revolved. In the end of one of these limbs, which is called the *pad*, the piece of steel by which the boring is performed, is inserted; the other limb is connected with a broad head, rather convex externally, which head, is placed against the breast, and is stationary while all the other parts are revolved.

The piece of steel inserted in the stock is called the *bit;* as it can readily be taken out or put in, the same stock serves for bits of all sizes. They are differently shaped, according to their use. The gouge-bit is best adapted for boring small holes in soft wood; it is shaped nearly like the turner's gouge, but is rather more pointed like a spoon at the extremity; the basil is made in the inside, and the sides are brought to a cutting edge, like those of a gimblet. The centre-bit has a small conical point projecting from the lower end; this point entering the wood first, keeps the tooth of the bit from wandering out of its proper course, and the hole is bored straight with great ease. The taper shell-bit is used for widening holes; it differs from the gouge-bit chiefly in tapering gradually from the pad to the lower extremity.

The bit for widening the upper part of a hole, to admit the head of a screw, is called a *countersink*. The head of the countersink is conical, and the cutting edge is single when made for wood alone, and stands out a little from the side of the cone. Joiners and cabinet-makers, however, are generally provided with countersinks for brass, and these, which have ten or a dozen teeth on the surface running slantwise from the base up the sides of the cone, they frequently make use of for wood, especially when it is hard, and they are anxious to avoid tearing it; for the teeth of the brass countersink act like those of a file.

The *gimblet* is a boring implement too well known to require any explanation of its construction; but with respect to its management, it may not be wholly useless to remind the novice, that, like other boring tools of a similar conformation, it requires to be withdrawn to remove the core as often as the cup or groove is filled, and this will be sooner or later, not only in proportion to the depth penetrated, but the density of the wood. Indeed, in boring such wood as lignum-vitæ, which clogs the tool, it is advisable to withdraw the gimblet, to clear away the core, before the cup is full. The auger gives warning of the time to stop, by the difficulty of turning it, when surcharged with shavings, and is too strong a tool to be in danger of being twisted; but the smallness of the gimblet renders it liable to be twisted and broken before the workman is aware, if not often enough withdrawn and emptied.

Gimblets which are broken-pointed, or blunted on the arris of the screw, are generally thrown aside, it being tedious, and laborious also when they are large, to work with them in such a state; but we may observe, that though the grindstone cannot be employed to sharpen the worm, a file may, so that a few minutes' labour will render them fit for use again.

The smallest sort of boring tool is a kind of bodkin, called the *brad-awl*, or *sprig-bit*, as it is chiefly used in making the perforation to admit those small slender nails, which have no head except a trifling projection on one side, and are called brads in some parts of the country, and sprigs in other parts. The sprig-bit is generally made with a shoulder where the tang terminates; below the shoulder it is cylindrical, to within a short distance of the extremity, which is flattened, and thereby made rather broader than the diameter of the cylindrical part; but so thin at the same time towards the end, as to form an edge. Unlike other boring tools, the sprig-bit takes away no part of the substance of the wood, nor is it turned entirely round in making a hole, but merely wrought backwards and forwards about half round before the motion is reversed.

The Hammer—Mallet—Square—Bevel—Mitre-square—Gauge—Straight-edge—Winding-sticks.

Though hammers, of various sizes, are indispensable in the working of wood, yet we may pass over the consideration of them in this place, with little more than referring to what has been already said with respect to them, in treating of the working of metals. The object of having the head of the hammer perfectly well secured to the handle is certainly well worth attention, from the serious accidents which may attend the neglect of it; but to attain it, we recommend not the use of those hammers which have plates of iron extending from the head, forming a kind of socket for the reception of the handle. These plates, it is true, afford ample means of uniting the head and the handle; but they render the latter inflexible at the very part where it is desirable there should be some spring. Hence those hammers are best, in which the handle simply passes through a perforation in the head, wooden wedges being driven in at the end of it, after it has been tightly fitted, to make it fast. If the aperture in the head be rather wider at the back than where the handle enters, and the wedges be dipped in glue before they are driven in, the fastening may be made complete. To admit the wedges, the end of the handle is cut a little way down with a saw.

The *mallet* is in effect a hammer, but is made of wood; it consequently does not damage substances struck with it so

much as the hammer, while presenting a large surface with an equal weight, it is more easy to hit the ends of the chisels, &c. with it. Mallets are made of the soundest and toughest wood which can be found; either ash or beech, or the hardest kind of elm, is usually preferred. They are mostly made rather concave on that side which the handle enters, and convex on the other; this is done because it is customary, or because it is supposed to look best: the diameter of the convex end, measured at right angles to the handle, is greater than that of the concave one, consequently the ends with which objects are struck are not parallel with the handle, but inclined to it and to each other; this is done for convenience, for the mallet is generally used in such a manner that the end with which the blow is made, notwithstanding its obliquity with respect to the handle, is parallel with the surface struck.

The *squares* used by joiners and cabinet-makers are frequently manufactured by these artists for their own use, in which case they are made of wood; but these wooden squares are always so much inferior in point of durability, and generally in point of correctness, to those sold by the ironmongers, at very reasonable rates, and which are made partly of wood and partly of metal, that we shall only notice the latter kind. The blade is a thin plate of steel, at a spring temper, of equal thickness in every part, and the opposite edges, or at least the two edges in the direction of its length, are correctly parallel with each other. The stock or wooden part is of considerable thickness, seldom less than half an inch in the smallest squares, such, for example, as are only three or four inches long, and the blades of which are not above a twelfth of that thickness. The blade is let into the stock so as to form a right angle with it both internally and externally. The mortise or kerf which receives the blade, is made at one end, in the middle and entirely across its breadth; great care is taken to make it parallel with the sides of the stock, but it is not cut so deep as to take in the whole breadth of the blade, the part left out being partly designed to admit of the outer edge being repaired, when worn. The inner edge of the stock, which forms one side of the interior square, is faced with brass. The stock, from its thickness, forms, on each side of the blade, a shoulder, which being pressed against one edge of a piece of wood, acts as a guide or stop to keep the blade (which is extended over the adjoining surface) at right angles to the arris, while a line is drawn along its outer edge. The interior square is mostly used for examining the squareness of a piece of stuff, and not for drawing lines. In this case, the sides of the square are not held parallel with, but perpen-

dicular to the piece examined. The mode of ascertaining the correctness of the square, used in the working of metals, has been already detailed, and will probably suggest the proper method of trying the square now described. Here we have no occasion for a ledge, the shoulder is pressed against the edge of a rectangular piece of stuff, and a line drawn close to the blade; the square is then turned over, and another line drawn as in the former case, and consequently if the instrument deviates from a correct figure, the error is detected upon the same principle as before.

The *bevel* consists of a blade and stock similar to those of the square, from which it differs only in one particular, viz. that the blade is moveable, and can therefore be set at any angle which may be required. The joint should be stiff, otherwise the bevel cannot be depended on for remaining as it has been set. Though rarely practised among the workers in wood, it certainly would be easy in all cases to adapt a screw to the bevel, so as to hold the blade firmly at any angle desired. The stone-masons generally take this precaution.

The *mitre-square* is a bevel, the blade of which is immoveably fixed in the stock, and is commonly set for marking an angle of forty-five degrees, this angle being more frequently required in joinery than any other angle except the right angle. Pieces of stuff bevelled at their extremities, and joined by placing two of the bevelled surfaces together, are said to be mitred. Mitring is often used in plane work; but when the pieces to be joined at an angle, are moulded, and the continuation of the mouldings is not to be broken, it is absolutely necessary. Hence its frequent use; instances of it occur at the corners of rooms, where the skirting boards of two different sides meet, in the surbase under the same circumstances, at the angles of picture-frames, &c.

The *gauge* is an instrument consisting of a stem, usually in the form of a square prism, with a small steel point, nearly at the end of one of the surfaces in the direction of its length, and just projecting enough to mark distinctly when pressed upon wood; the stem passes at right angles through a mortise in the middle of a piece of wood called the head, to which it is about equal in point of thickness; but those surfaces of the head through which the mortise passes, should not be less than three times the diameter of the stem. The head can be set at any distance required from the steel point, and there secured by a small wedge, passing through a mortise in one of its sides, and bearing upon the stem. The use of the gauge is to draw lines parallel to the arris of a piece of stuff, to serve as a guide for the saw, the plane, or the chisel. In

drawing the line, it is necessary to keep that side of the head which is next the steel point rather firmly pressed against the edge of the stuff, otherwise the point will be apt to deviate from its proper course, if it meet with knots or irregularities in the grain.

A gauge made with two points projecting on the same side, and one of which (being moveable in a groove or mortise) can be placed at any distance from the other, is called a *mortise-gauge;* it is used alike in gauging mortises and tenons.

Though the steel straight-edge is hardly known even by name to a great majority of the artists who work in metal, yet the *wooden straight-edge* is familiar enough to most who work in wood. Wooden straight-edges should be made of stuff exceedingly well seasoned; it is usual to make two at the same time; the sides are first made true, and each piece of equal thickness; they are then placed against each other, and fastened in the cheeks of the bench-screw, in which situation their upper edges are planed true with the assistance of a straight-edge which can be depended on, or as nearly true as can be determined by the eye, if we cannot readily obtain a straight-edge for the trial. When the pieces are supposed to be true, they are taken out of their situation, and the edges last planed are placed upon each other. If the surfaces coincide so exactly than no light can pass between them, the straight-edges are finished; but if any error be detected, the planing with the jointer must be renewed in the same manner as before, and the examination repeated till the result is satisfactory. The use of the straight-edge, in ascertaining the straightness of other surfaces, is not inconsiderable.

Winding-sticks are always used in pairs, and the use of them constitutes another contrivance for determining the levelness of any given surface, that the workman may reduce it more or less in any particular part, in order to make it true. Straight-edges are customarily finished only on one edge; but if both edges were finished, and they were made correctly rectangular, that is, of equal breadth through their whole length, they would answer the end of winding-sticks, which are used in the following manner: one of them is placed at each end of the surface to be examined, the eye is then directed from the uppermost edge of the nearer one to that perpendicular side of the further one, which is next the observer. If the eye be elevated or depressed, till one end of the nearer winding-stick intercepts the view of the opposite perpendicular side of the other, and the other two ends are observed to have the same relative situation, the ends of the surface examined are already in the same plane. But if the nearer winding-stick will not

intercept an equal portion at each end of the further one, the part found to be too high must be reduced till this is the case. It is always proper to examine the surface by placing the winding-sticks in various situations, but especially across near the corners, so that the eye may look at them diagonally.

Draw-bore pins are used in forcing a tenoned piece into its proper place in the mortise. They are made with tangs and shoulders, and fitted into handles like chisels. Below the shoulder they are round, and taper slightly to within a short distance of the point, where they are turned off to cones, like the extremities of an axis running in hollow centres. To use them, bore a hole through the mortise-cheeks, at the place where the pin intended to fasten the mortised and tenoned piece together will be required, and which is generally made nearer the shoulders than the end of the tenon. Insert the tenon, and when it is as nearly in its proper place as it can be driven, mark it on both sides through the hole in the mortise-cheeks. Take out the tenon, and bore it through, a little nearer its shoulders than the centre of these marks; insert it again in the mortise, and use the draw-bore pins by entering them at the holes, to draw its shoulders against the abutments. The use of the draw-bore pins, also, condenses or hardens the wood on the sides of the holes, and when the wooden peg is driven in, it has, on this account, a better hold. This is, indeed, their principal use at present, as the cramping-frame, which acts by means of a screw, is much more powerful in forcing the shoulders of tenons against their abutments; but the draw-bore pins, or some substitute for them, will obviously be convenient to those who may occasionally require means to force tenons to their bearings, without possessing a complete apparatus.

Of Glue.

To prepare glue, it must be steeped for a number of hours, over night, for instance, in cold water, by which means it will become very considerably swelled and softened. It must then be gently boiled, till it is entirely dissolved, and of a consistence not too thick to be easily brushed over wood. About a quart of water may be used to half a pound of glue. The heat employed in melting glue should not be more than is required to make water boil; and to avoid burning it, the joiners, &c. as is well known, suspend the vessel containing it in another vessel containing only water, which latter vessel is generally made of copper, in the form of a common tea-kettle without a spout, and alone receives the direct influence of the fire.

The circumstances most favourable to the best effect which glue can produce, in uniting two pieces of wood, are the following: that the glue should be thoroughly dissolved, and used boiling hot at the first or second melting; that the wood should be warm and perfectly dry; that a very thin covering of glue be interposed at the juncture, and that the surfaces to be united, be strongly pressed together, and left in that state, in a warm but not hot situation, till the glue is completely hard. In veneering, and for all very delicate work, the whole of these requisites, as they not only ensure the strongest joint, but the glue sets the soonest, should be combined in the operation; but on some occasions this is impossible, and therefore the most essential must be regarded, such as the hotness of the glue, and the dryness of the wood. When the faces of joints, particularly those that cannot be much compressed, have been besmeared with glue, which should always be done with the greatest expedition, they should be rubbed lengthwise one upon another two or three times, to settle them close.

When glue, by repeatedly melting it, has become of a dark and almost black colour, its qualities are impaired; when newly melted, it is of a light ruddy brown colour, nearly like that of the dry cake held up to the light; and while this colour remains, it may be considered fit for almost every purpose.

Though glue which has been newly melted is the most suitable for use, other circumstances being the same, yet that which has been the longest manufactured is the best. To try the goodness of glue, steep a piece three or four days in cold water; if it swell considerably without melting, and when taken out resumes, in a short time, its former dryness, it is excellent. If it be soluble in cold water, it is a proof that it wants strength.

A glue which does not dissolve in water, may be obtained by melting common glue with the smallest possible quantity of water, and adding by degrees linseed oil rendered drying by boiling it with litharge; while the oil is added, the ingredients must be well stirred to incorporate them thoroughly.

A glue which will resist water, in a considerable degree, is made by dissolving common glue in skimmed milk.

Finely levigated chalk added to the common solution of glue in water, constitutes an addition which strengthens it, and renders it suitable for sign-boards, or other things which must stand the weather.

A glue that will hold against fire or water, may be prepared by mixing a handful of quick lime with four ounces of linseed oil: thoroughly levigate the mixture, boil it to a good thickness, and then spread it on tin plates in the shade; it will become

exceedingly hard, but may be dissolved over a fire, as ordinary glue, and is then fit for use.

Several glues, such as that of isinglass, which, for a variety of reasons, are not used in the common course of business among joiners and cabinet-makers, we shall speak of particularly under the head Cements.

Of the Mortise and Tenon.

The proportion which mortises and tenons ought to bear to the wood, under different circumstances, has never been demonstrated by experiments made for that purpose. It is common practice, therefore, alone, which dictates the rules to be observed. In general the tenon is one-third of the thickness of the stuff; but when the mortise and tenon are intended to lie horizontally, and the juncture will be unsupported, the tenon should not be more than one-fifth of the thickness of the stuff, otherwise a strain or weight on the upper surface of the tenoned piece would probably split off the under cheek of the mortise, while the tenon itself remained sound.

In joining two pieces of timber, so that the tenoned piece shall not pass the end of the mortised piece, to prevent the necessity of cutting open the side of the mortise, the tenon must be reduced one-third or at least one-fourth of its breadth. In either case, the mortise will still be so near the end of the piece in which it is made, as to be split by a small force in driving in the tenon. To prevent this accident, it is customary, on such occasions as admit of the precaution being taken, to make the end beyond the mortise considerably longer than it is intended to remain; the tenon may then be driven tightly in, and the superfluous wood afterwards cut off.

The above proportions for the mortise and tenon, refer to the joining of timber, like dimensions of which are of the same strength, and therefore it will be necessary to vary them, according as one piece is weaker or stronger than the other.

In making deep mortises, especially in hard wood, it is customary to shorten the labour, by commencing it with boring a number of auger holes, the compartments between which are speedily cut away with the chisel.

In neat work, before a saw is employed to cut the shoulder of a tenon, nick the place with a paring chisel; the saw will not then tear the wood, and the line of its entrance may be correctly determined.

When the mortise is to pass entirely through a piece of stuff, the space allotted for it is gauged on both sides with the greatest precision, and when it has been half cut from one side, the remaining half is cut from the opposite one. By this means,

if there be any error in the direction of the chisel, it is of little consequence, the irregularity being confined to the middle of the mortise. The sides of the mortise should, however, be made as even as possible, that they may every-where come in contact with the sides of the tenon.

The sides of a mortise that passes through the stuff, should be inclined to each other a little towards the shoulders of the tenon, because the latter, after it is driven in, is expanded by wedges.

We cannot close these details of the primary operations by which metals and timber are fitted for mechanical purposes, without offering a few sentiments to the consideration of the young artist interested in them, whether he is one who is anxious to excel in a particular branch of art, as affording the means of honourable livelihood; or claims merely the appellation of an amateur, who studies mechanical operations from the love of knowledge, the desire of amusement, or the hope of celebrity in making discoveries or improvements. Let him not be discouraged by the failure of first attempts. Instead of losing his time in uselessly regretting his disappointment, let him examine into the cause of it, and promptly repeat his experiments with more precaution. It is a mistaken idea, that manual dexterity is absolutely dependent upon length of practice; uncommon are the cases in which it fails to be the early reward of those who unite perseverance—patient and prompt, with an attention ever alive to avail themselves of every new light which the liberality of others, or the course of their own experience, supplies. But those who postpone ardent exertion, by satisfying themselves with the hope, that length of practice will perfect them, will in the end regret their delusion, and may ineffectually try to recover their loss, when habitual languor, and other injurious habits, have rendered the mind averse to observe, and the hand unable to perform.

Much might be said on this subject, but we forbear a lengthened disquisition; yet we cannot omit observing, that those who take an early delight, and attain an early proficiency in mechanical arts, are preparing an excellent groundwork for investigations of a higher order. They are acquiring, in the disguise of amusement, that dexterity of hand, and facility of contrivance, that readiness in supplying their casual wants, and habit of methodical arrangement, which will afterwards qualify them to explore the paths of knowledge through the medium of philosophical experiment; and in proportion as

these interest their attention, they will be disposed to study in earnest the fundamental principles of science.

It may be well for the young artists we are addressing, to be apprized, that to make any useful proficiency in mechanical pursuits, to be distinguished for skill and promptitude of execution, requires a degree of patient assiduity, of which few who have been brought up at the desk or behind the counter, can form any adequate idea; and who, therefore, would be uneasy and unhappy, under a degree of exertion which they must learn to display without entertaining a sentiment of its hardship. Let them not, however, be disheartened at the prospect; the habits indispensable to their full success, if acquired, allowed their due influence, and guided by moral prudence, are of inestimable value: they are extending the means of multiplying their comforts; they are increasing the power of the head to contrive as well as of the hand to execute, and the steadiness of attention superinduced, will be beneficial to them in every action of their lives.

All know, but few act as if they believed, that, accident out of the question, success in the general issue of our exertions, is made up of success in little matters, or individual operations. Let us then be allowed to impress this truism upon the reader's mind, and to elucidate it by stating, that if two workmen have each fifteen thousand motions to make in ten hours, he who shall perform each motion half a second more quickly than the other, will terminate his labour two hours sooner! Two hours of spare time may be employed to great advantage; yet what is half a second considered by itself? and by how many may this economy of time be practised, without a perceptible addition of fatigue? The quantity of labour is no criterion of the fatigue it will occasion, even to those who are alike in corporal power. The sentiments by which we are actuated in the performance of a task, have a paramount influence; languor of mind prematurely exhausts the body, and the weariness experienced is often disproportioned to the animal strength possessed. But our sentiments are much under our control, and it surely should be our study to cherish those, which by inspiring alacrity of exertion, are essentially conducive to our interest. To the labourer, there is the prospect of commanding respect, and of bettering his condition; to the amateur, besides the common, daily advantages of knowledge, and the indeprivable gratification which the acquirement of it affords, there is the animating hope, that if discoveries crown his exertions, he may be considered a benefactor to mankind.

ARCHITECTURE.

The science of Architecture may be considered, in its most extended application, to comprehend building of every kind; but at present we must consider it in one much more restricted, according to which, Architecture may be said to treat of the planning and erection of edifices, which are composed and embellished after certain long established rules, according to two principal modes,

1st, the English or Gothic,

2nd, the Antique, or Grecian and Roman.

We shall treat of these modes in distinct dissertations, because their principles are completely distinct, and indeed mostly form direct contrasts. But before we proceed to treat of them, it will be proper to make a few remarks on the distinction between mere house-building, and that higher character of composition in the Grecian and Roman orders, which is properly styled Architecture; for though we have now very many noble architectural houses, we are much in danger of having our public edifices debased, by a consideration of what is convenient as a house, rather than what is correct as an architectural design.

In order properly to examine this subject, we must consider a little, what are the buildings regarded as our models for working the orders, and in what climate, for what purposes, and under what circumstances, they were erected. This may, per haps, lead to some conclusions, which may serve to distinguish that description of work, which, however rich or costly, is still mere house-building, in point of its composition.

It is acknowledged, on all hands, that our best models, in the three ancient unmixed orders,—the Doric, Ionic, and Corinthian, are the remains of Grecian temples. Most of them were erected in a climate, in which a covering from rain was by no means essential, and we shall find this circumstance very influential; for as the open space within the walls was always partially, and often wholly open, apertures in those walls for light, were unnecessary; and we find, also, in Grecian structures, very few, sometimes only one door. The purpose for which these buildings were erected, was the occasional reception of a large body of people, and not the settled residence of any. But, perhaps, the circumstances under which they were erected, have had more influence on the rules which have been

handed down to us, as necessary to be observed in composing architectural designs, than either the climate or their use. It is now pretty generally agreed, that the Greeks, if they were acquainted with the mathematical properties of the arch, did not use it till it was introduced by the Romans. Here then we see at once a limitation of the intercolumniation, which must be restrained by the necessity of finding stones of sufficient length to form the architrave. Hence the smaller comparative intercolumniations of the Grecian buildings, and the constant use of columns; and hence the propriety of avoiding arches, in compositions of the purer Grecian orders.

The Romans introduced the arch very extensively, into buildings of almost every description, and made several alterations in the mode of working the orders they found in Greece, to which they added one order, by mixing the Corinthian and Ionic, and another by stripping the Doric of its ornaments. Their climate, also, was so far different as to require more general roofing, but still, from the greater necessity of providing a screen from the heat of the sun, than apertures to admit the light, it does not appear that large windows were in general use, and hence an important difference in modern work. Although, by roofs and arches, much more approximated to modern necessities than the Grecian models, still those of Rome which can be regarded as models of composition, are temples, or rather public edifices, and not domestic buildings, which, whenever they have been found, appear variously unadapted to modern wants, and therefore unfit for imitation.

In a few words we may sum up the grand distinctions between mere building and architectural design:—the former looks for convenience, and though it will doubtless often use architectural ornaments, and preserve their proportions, when used as smaller parts, yet the general proportion may vary very widely from the orders, and yet be pleasing, and perhaps not incorrect;—but all this is modern building, and not architecture in its restricted sense; in this the columns are essential parts, and to them and their proportions all must be made subservient; and here we may seek, with care and minuteness, amongst the many remains yet left in various parts, (and of which the best are familiar to most, from the valuable delineations we possess of those who have accurately examined them,) for models, and in selecting and adopting these, the taste and abilities of the architect has ample space.

As an introduction to the dissertations, it may not be amiss to take a hasty sketch of the progress of Architecture in England.

Of the British architecture, before the arrival of the Ro-

mans in the island, we have no clear account; but it is not likely it differed much from the ordinary modes of uncivilized nations; the hut of wood with a variety of coverings, and sometimes the cavities of the rock, were doubtless the domestic habitations of the aborignal Britons; and their stupendous public edifices, such as Stonehenge and others, still remain to us. The arrival of the Romans was a new era; they introduced, at least in some degree, their own architecture, of which a variety of specimens have been found; some few still remain, of which, perhaps, the gate at Lincoln is the only one retaining its original use. Although some fine specimens of workmanship have been dug up in parts, yet by far the greatest part of the Roman work was rude, and by no means comparable with the antiquities of Greece and Italy, though executed by the Romans. When they left the island, it was most likely that the execution of the Britons was still more rude, and endeavouring to imitate, but not working on principle the Roman work, their architecture became debased into the Saxon and early Norman, intermixed with ornaments perhaps brought in by the Danes. After the conquest, the rich Norman barons, erecting very magnificent castles and churches, the execution manifestly improved, though still with much similarity to the Roman mode debased; but the introduction of shafts, instead of the massive pier, first began to approach that lighter mode of building, which, by the introduction of the pointed arch, and by an increased delicacy of execution, and boldness of composition, ripened, at the close of the twelfth century, into the simple, yet beautiful early English style. At the close of another century, this style, from the alteration of its windows, by throwing them into large ones, divided by mullions, introducing tracery in the heads of windows, and the general use of flowered ornaments, together with an important alteration in the piers, became the decorated English style, which may be considered as the perfection of the English mode. This was very difficult to execute, from its requiring flowing lines where straight ones were easier combined; and at the close of the fourteenth century, we find these flowing lines giving way to perpendicular and horizontal ones, the use of which continued to increase, till the arches were almost lost in a continued series of pannels, which, at length, in one building, the chapel of Henry the VII. covered completely both the outside and inside, and the eye, fatigued by the constant repetition of small parts, sought in vain for the bold grandeur of design which had been so nobly conspicuous in the preceding style. The Reformation, occasioning the destruction of many of the buildings the most celebrated, and mutilating others, or abstracting the funds

necessary for their repair, seems to have put an end to the working of the English styles on principle. The square pannelled mullioned windows, and wooden pannelled roofs and halls, of the great houses of the time of queen Elizabeth, seem rather a debased English than any thing else; but during the reign of her successor, the Italian architecture began to be introduced, first only in columns of doors, and other small parts, and afterwards in larger portions, though still the general style was this debased English. Of this introduction, the most memorable was the celebrated portico of the schools at Oxford, where, into a building adorned with pinnacles, and having mullioned windows, the architect has crowded all the five orders over each other. Some of the works of Inigo Jones are little removed beyond this barbarism. Longleat, in Wiltshire, is a little more advanced, and the banqueting-house, Whitehall, seems to mark the complete introduction of Roman workmanship. The close of the seventeenth century produced Sir Christopher Wren, a man whose powers, confessedly great, lead us to regret he had not studied the architecture of his English ancestors, with the success which he did those of Rome; for while he has raised the most magnificent modern building we possess, he seems to have been pleased to disfigure the English edifice he had to complete. While his works at St. Mary, Aldermary, Bow-lane, and St. Dunstan in the East, prove how well he could execute imitated English buildings, when he chose, though even in them he has variously departed from the true English principles. By the end of the seventeenth century, the Roman architecture seems well established, and the works of Vitruvius and Palladio successfully studied; but Sir John Vaubrugh and Nicholas Hawksmoor seem to have endeavoured to introduce a massiveness of style which happily is peculiar to themselves. The works of Palladio, as illustrated by some carpenters, seem to have been the model for working the orders during the greatest part of the eighteenth century, but in the early and middle part of it, a style of ornament borrowed from the French was much intoduced in interiors, the principal distinctions of which were the absence of all straight lines, and almost of any regular lines.

The examples of this are now nearly extinct, and seem to have been driven out by the natural operation of the advance of good workmanship in the lower class of buildings. All ornamental carvings were difficultly executed in wood, and were very expensive; but towards the latter end of the eighteenth century, the Adams's introduced a style of ornament directly contrary to the heavy carving of their predecessors. This was so flat, as to be easily worked in plaster and other compositions

and ornament being sold very cheap, was profusely used in carpenter's work. This flatness was more or less visible in many considerable buildings; but near the close of the century, the magnificent works of Stuart and Revet, and the Ionian antiquities of the Dilletante Society, began to excite the public attention, and in a few years a great alteration was visible; the massive Doric, and the beautiful plain Grecian Ionic, began to be worked, and our ordinary door-cases, &c. soon began to take a better character. The use of the simple, yet bold mouldings and ornaments of the Grecian models, is gradually spreading, and perhaps we may hope, from the present general investigation of the principles of science, that this will continue without danger of future debasement, and that a day may come when we shall have Grecian, Roman, and English edifices, erected on the principles of each.

As the earliest in point of execution in England, we shall begin with the dissertation on

ENGLISH ARCHITECTURE.

In a work like the present, there will be little propriety in lengthened disquisitions on the origin of this mode of building; but much service may be rendered to individuals, by a clear detail of those distinctions, which, being once laid down with precision, will enable persons of common observation, to distinguish the difference of age and style in these buildings, as easily as the distinctions of the Grecian and Roman orders.

During the eighteenth century, various attempts, unaer the name of Gothic, have arisen in repairs and rebuilding of ecclesiastical edifices; but these have been little more than making clustered columns and pointed windows, every real principle of English architecture being, by the builders, either unknown or totally neglected.

English architecture, then, which has been too long called Gothic, may be divided into four distinct periods, or styles, which may be named,

1st, the Norman style,
2nd, the Early English style,
3rd, the Decorated English style, and
4th, the Perpendicular English style.

The dates of these styles we shall state hereafter, and it may be proper to notice, that the clear distinctions are now almost entirely confined to churches; for the destruction and alteration of castellated buildings has been so great, from the alterations



of the modes of warfare, &c. that, in them, we can hardly tell which is original and which addition.

Before we enter on a description of the styles separately, it will be necessary to explain a few terms which are made use of in describing churches, &c. and without understanding which, it will be impossible to comprehend the subject clearly.

Most of the ancient ecclesiastical edifices, when considered complete, were built in the form of a cross, with a tower, lantern, or spire erected at the intersection. The interior space was usually thus divided:

The space westward of the cross is called the *nave*.

The divisions outward of the piers are called *aisles*.

The space eastward of the cross is generally the *choir*.

The part running north and south is called the *cross* or *transept*.

The choir is generally enclosed by a *screen*, on the western part of which is usually placed the organ.

The choir, in cathedrals, does not generally extend to the eastern end of the building, but there is a space behind the altar, usually called the *lady chapel*.

The choir is only between the piers, and does not include the side aisles, which serve as passages to the lady chapel, altar, &c.

The transept has sometimes *side aisles*, which are often separated by screens for chapels.

Chapels are attached to all parts, and are frequently additions.

The aisles of the nave are mostly open to it, and in cathedrals both are generally without pews.

In churches not collegiate, the eastern space about the altar is called the *chancel*.

To the sides are often attached small buildings over the doors, called *porches*, which have sometimes vestries, schools, &c. over them.

The *font* is generally placed in the western part of the nave, but in small churches its situation is very various.

In large churches, the great doors are generally either at the west end, or at the end of the transepts, or both; but in small churches, often at the sides.

To most cathedrals are attached a *chapter-house* and *cloisters*, which are usually on the same side.

The *chapter-house* is often multangular.

The *cloisters* are generally a quadrangle, with an open space in the centre; the side to which is a series of arches, originally glazed, now mostly open. The other wall is generally one side

of the church or other buildings, with which the cloisters communicate by various doors. The cloisters are usually arched over, and formed the principal communication between the different parts of the monastery.

The lady chapel is not always at the east end of the choir; at Durham it is at the west end of the nave; at Ely, on the north side.

The choir sometimes advances westward of the cross, as at Westminster.

The spaces in the interior, between the arches, are *piers.*

The windows above the arches, which appear on the out side over the roof of the aisles, are called *clerestory windows.*

Any building above the roof may be called a *steeple.* If it be square-topt, it is called a *tower.*

A tower may be round, square, or multangular. The tower is often crowned with a spire, and sometimes with a short tower of light work, which is called a *lantern.* An opening into the tower, in the interior, above the roof, is also called a lantern.

Towers of great height in proportion to their diameter, are called *turrets;* these often contain staircases, and are sometimes crowned with small spires.

Large towers have often turrets at their corners, and often one larger than the others, containing a staircase; sometimes they have only that one.

The projections at the corners, and between the windows, are called *buttresses.*

The walls are crowned by a *parapet,* which is straight at the top, or a *battlement,* which is indented; both may be plain or sunk, pannelled or pierced.

Arches are round, pointed, or mixed:

A *semi-circular arch* has its centre in the same line with its spring.

A *segmental arch* has its centre lower than the spring.

A *horse-shoe arch* has its centre above the spring.

Pointed arches are either, *equilateral*—described from two centres, which are the whole breadth of the arch from each other, and form the arch about an equilateral triangle; or *drop arches,* which have a radius shorter than the breadth of the arch, and are described about an obtuse-angled triangle; or *lancet arches,* which have a radius longer than the breadth of the arch, and are described about an acute-angled triangle.

All these pointed arches may be of the nature of segmental arches, and have their centres below their spring.

Mixed arches are of three centres, which look nearly like elliptical arches; or of four centres, commonly called the *Tudor*

arch; this is flat for its span, and has two of its centres in or near the spring, and the other two far below it.

The *ogee,* or *contrasted arch,* has four centres; two in or near the span, and two above it, and reversed.

The spaces included between the arch and a square formed at the outside of it, are called *spandrells,* and are often ornamented.

Windows are divided into lights by *mullions.*

The ornaments of the divisions at the heads of windows, &c. are called *tracery.* Tracery is either *flowing,* where the lines branch out into leaves, arches, &c.; or *perpendicular,* where the mullions are continued through in straight lines.

The horizontal divisions of windows, &c. are called *transoms.*

The parts of tracery are ornamented with small arches and points, which is called *feathering* or *foliation,* and the small arches *cusps,* and according to the number in immediate connection, they are called *trefoil, quatrefoil, cinquefoil,* &c. for which see the plate.

The cusps are sometimes again feathered, and this is called *double feathering.*

Tablets are small projecting mouldings, or strings, mostly horizontal.

The tablet at the top, under the battlement, is called a *cornice,* and that at the bottom a basement, under which is generally a thicker wall.

The tablet running round doors and windows, is called a *drip-stone,* and if ornamented, a *canopy.*

Bands are either small strings round shafts, or a horizontal line of square, round, &c. pannels, used to ornament towers, spires, &c.

Niches are small arches, mostly sunk in the wall, and ornamented often very richly with buttresses, canopies, &c.

A *corbel* is an ornamented projection from the wall, to support an arch, niche, &c. and is often a head or part of a figure or animal.

A *pinnacle* is a small spire, generally square and ornamented, which is usually placed on the tops of buttresses, both external and internal.

The small bunches of foliage ornamenting canopies, pinnacles, &c. are called *crockets.*

The larger bunches on the top are called *finials,* and this term is sometimes applied to the whole pinnacle.

The seats for the dean, canons, &c. in the choirs of collegiate churches, are called *stalls.*

The bishop's seat is called his *throne.*

The ornamental open work over the stalls, and in general any minute ornamental open work, is called *tabernacle work*.

In some churches, not collegiate, there yet remains a screen, with a large projection at the top, between the nave and chancel, on which was ancieptly placed certain images; this was called a *rood loft*.

Near the entrance door is sometimes found a small niche, with a basin, which held, in catholic times, their holy water; these are called *stoups*.

Near the altar, or at least where some altar has once been placed, there is sometimes found another niche, distinguished from the stoup by having a small hole at the bottom to carry off the remains of the consecrated wine; this is called a *piscina;* it is often double, with a place for the bread.

On the south side, at the east end of some churches, are found stone walls, either one, two, or three; of which the uses have been much contested.

Under several large churches, and some few small ones, are certain vaulted chapels, these are called *crypts*.

In order to render the comparison of the different styles easy, we shall divide the description of each into the following sections:

Doors,
Windows,
Arches,
Piers,
Buttresses,
Tablets,
Niches, and ornamental arches, or pannels,
Ornamental carvings,
Steeples;

And at the end of the styles will be noticed, in one series, the sections of battlements and roofs.

We shall first give, at one view, the date of the styles, and their most prominent distinctions, and then proceed to the particular sections as described above.

1st, the *Norman Style*, which prevailed to the end of the reign of Henry II, in 1189; distinguished by its arches being generally semi-circular, and not pointed, with bold and rude ornaments. This style seems to have commenced before the conquest, but we have no remains *really known* to be more than a very few years older.

2nd, the *Early English Style*, reaching to the end of the reign of Edward I, in 1307; distinguished by pointed arches, and long narrow windows, without mullions; and a peculiar toothed ornament, more fully described hereafter.

3d, *Decorated English*, reaching to the end of the reign of Edward III, in 1377, and perhaps from ten to fifteen years longer. This style is distinguished by its large windows, which have pointed arches divided by mullions, and the tracery in flowing lines of circles, arches, &c. and not running perpendicularly; its ornaments rich, and very delicately carved; and ornament used to very great extent, yet seldom crowded.

Perpendicular English. This is the last style, and appears to have been in use, though much debased, even perhaps as far as to 1630 or 1640, but only in additions. Probably the latest whole building is not later than Henry VIII. The name clearly designates this style, for the mullions of the windows, the ornamental pannelling, &c. run in perpendicular lines, and form a complete distinction from the last style, and the richer buildings are often so crowded with ornament, as to destroy the beauty of the design. The carvings are generally very delicately executed.

It may be necessary to state, that though many writers speak of Saxon buildings, those which they describe as such, are either known to be Norman, or are so like them, that there is no real distinction. But it is most likely, that in some obscure country church tower, &c. some *real* Saxon work of a much earlier date may exist; hitherto, however, none has been ascertained to be of so great an age.

We shall now begin to trace

The First, or Norman Style.

Norman Doors.

There seems to have been a desire in the architects who succeeded the Normans, to preserve the doors of their predecessors, whence we have so many of these noble, though, in most cases, rude efforts of skill, remaining. In many small churches, where all has been swept away, to make room for even *perpendicular* alterations, the Norman door has been suffered to remain. They are varied, yet there is no prominent distinction to make it necessary to subdivide them. The arch is semi-circular, and the mode of increasing their richness, was by increasing the number of bands of moulding, and of course the depth of the arch. Shafts are often used, but not always, and we find very frequently, in the same building, one door with shafts, and one without. When shafts are used there is commonly an impost moulding above them, before the arch mouldings spring. These mouldings are generally much ornamented, and the wave or zigzag ornament in some of its

diversities, is almost universal, as is a large round moulding, with the heads on the outer edge projecting their beaks over this moulding. There are also mouldings with a series of figures enclosed in a running ornament; and at one church at York, these figures are the zodiacal signs. The exterior moulding often goes down no lower than the spring of the arch, thus forming an apparent dripstone, though it does not project so as really to form one. The door is often square, and the interval to the arch filled with mouldings. Amongst the great variety of these doors in excellent preservation, it is difficult to point out particulars, but Iffley church, near Oxford, is perhaps the best specimen, as it contains three doors, all of which are different; and the south door is nearly unique, from the flowers in its interior mouldings. South Ockenden church, in Essex, has also a door of uncommon beauty of design and elegance of execution. Durham, Rochester, Worcester, and Lincoln cathedrals, have also fine Norman doors. In these doors, almost all the ornament is external, and the inside often quite plain.

There does not appear to have been any double Norman doors.

Norman Windows.

The windows, in this style, are diminutive doors as to their ornaments, except that, in large buildings, shafts are more frequent, and often with plain mouldings. The size of these windows is generally small, seldom, except in very large buildings, so large as even a small door; there are no mullions; the arch is semi-circular, and if the window is quite plain, generally sloped sides, either inside or out, or both; the bottom often nearly horizontal. The proportions of the Norman windows are generally those of a door, and very rarely, if ever, exceed two squares in height, of the exterior proportions, including the ornaments.

The existing Norman windows are mostly in buildings retaining still the entire character of that style; for in most they have been taken out, and others of later styles put in, as at Durham and many other cathedrals.

There are still remaining traces of a very few circular windows of this style; the west window at Iffley was circular, but it is taken out; there is one in Canterbury cathedral, which seems to be Norman; and there is one undoubtedly Norman at Barfreston, rendered additionally singular, by its being divided by grotesque heads, and something like mullions, though very rude, into eight parts.

There seems to have been little if any attempt at feathering

or foliating the heads of Norman doors or windows: but there is a singular door in the cloisters at Chester, with a semi-circular head, that has an ornament of this kind; but from its situation, and the alterations which have been made, it is uncertain whether it is original or not.

Norman Arches.

The early Norman arches are semi-circular, and in many instances this form of the arch seems to have continued to the latest date, even when some of the parts were quite advanced into the next style; of this the Temple church is a curious instance; here are piers with some of the features of the next style, and also pointed arches with a range of intersecting arches, and over this the old round-headed Norman window. But though the round arch thus continued to the very end of the style, the introduction of pointed arches must have been much earlier, for we find intersecting arches in buildings of the purest Norman, and whoever constructed them, constructed pointed arches; but it appears as if the round and pointed arches were for nearly a century used indiscriminately, as was most consonant to the necessities of the work, or the builder's ideas. Kirkstall abbey has all its work exteriorly round arches, but the nave has pointed arches in the interior. There are some Norman arches so near a semi-circle as to be only just perceptibly pointed, and still with the rudely carved Norman ornaments.

There are are a few Norman arches of very curious shape, being more than a semi-circle, or what is called a horse-shoe, and in a few instances a double arch. These arches have sometimes plain faces, but are much oftener ornamented with the zigzag, and other ornaments peculiar to this style.

Norman Piers.

These are of four descriptions, 1st, The round massive columnar pier, which has sometimes a round, and sometimes a square capital; they are generally plain, but sometimes ornamented with channels*in various forms, some plain zigzag, some like network, and some spiral. They are sometimes met with but little more than two diameters high, and sometimes are six or seven, and those with square-headed capitals are generally the tallest.

2nd, A multangular pier, much less massive, is sometimes used, generally octagonal, and commonly with an arch more or less pointed.

3d, The common pier with shafts; these have sometimes plain capitals, but sometimes much ornamented with rude

foliage, and occasionally animals. The shafts are mostly set in square recesses.

4th, A plain pier, with perfectly plain round arches in two or three divisions.

In some cases, the shafts are divided by bands, but the instances are very few.

Norman Buttresses.

These require little description; they are plain broad faces, with but small projection, often only a few inches, and often running up only to the cornice tablet, and there finishing under its projection. Sometimes they are finished with a plain slope, and in a few instances are composed of several shafts. Bands or tablets running along the walls, often run round the buttresses.

Norman Tablets.

In treating of tablets, that which is usually called the cornice is of the first consideration; this is frequently only a plain face of parapet, of the same projection as the buttresses; but under it there is often placed a row of blocks, sometimes plain, sometimes carved in grotesque heads, and in some instances the grotesque heads support small arches, in which case it is called a corbel table. A plain string is also sometimes used as a cornice.

The next most important tablet is the dripstone, or outer moulding of windows and doors; this is sometimes undistinguished, but oftener a plain round or square string, frequently continued horizontally from one window to another round the buttresses.

The other tablets under windows, &c. are generally plain slopes above or below a flat string. In the interior, and in some instances in the exterior, these are much carved in the various ornaments described hereafter.

Norman Niches, &c.

These, if so they may be called, are a series of small arches with round and often with intersecting arches, sometimes without, but oftener with shafts. Some of these arches have their mouldings much ornamented; but very few, if any, appear to have been intended for statues.

Norman Ornaments.

The ornaments of this style consist principally of the different kinds of carved mouldings surrounding doors and windows, and used as tablets. The first and most frequent of these is the

zigzag or chevron moulding, which is generally used in great profusion. The next most common on door mouldings, is the beak-head moulding, consisting of a hollow and a large round; in the hollow are placed heads of beasts or birds, whose tongues or beaks encircle the round. After these come many varieties, almost every specimen having some difference of composition; a good collection of these may be seen in the Archæologia, and King's Munimenta Antiqua.

The capitals of piers and shafts are often very rudely carved in various grotesque devices of animals and leaves; but in all, the design is rude, and the plants are unnatural.

Norman Steeples.

The Norman steeple was mostly a massive tower, seldom rising more than a square in height above the roof, and often not so much. They are sometimes plain, but often ornamented by plain or intersecting arches, and have generally the flat buttress, but that of St. Alban's runs into a round turret at each corner of the upper stage; and at St. Peter's, Northampton, there is a singular buttress of three parts of circles, but there is some doubt if it is not an addition. It does not seem likely we have any Norman spires, but there are some turrets crowned with large pinnacles, which may be Norman—such is one at Cleve in Gloucestershire, and one of the towers at the side of the west front of Rochester cathedral.

Having gone through the parts, it remains to speak of the general appearance of the Norman buildings, of which we have very few, if any, remaining unaltered. Almost all the west fronts, and many transept ends, have had new windows, but some small churches remain nearly entire. These present appearances of great solidity, but not much beauty; the exterior doors being generally the best portion. But though heavy and dark, from the smallness of the windows, some of the large Norman edifices, when complete, were very magnificent. Amply to show this, enough remains at Durham, Southwell, Gloucester, Rochester, &c. In imitating or restoring buildings of this style, the work should not be polished too highly, as all the Norman work remaining, is, however difficult of execution, still rude, and not finely polished.

Of the Second, or Early English Style.

Early English Doors.

As the Norman doors may be said to be all of semi-circular arches, these may be said to be all pointed, at least all the exterior ornamented ones; for there are small interior doors of this style with flat tops, and the sides of the top as it were supported by a quarter circle from each side. The large doors of this style are mostly double, the two being divided by either one shaft or several clustered, and a quatrefoil or other ornament over them. These doors are often as finely recessed as the Norman, but the bands and shafts are more numerous, being smaller; and in the hollow mouldings they are frequently enriched with the peculiar ornament of this style, a singular toothed projection, which, when well executed, has a fine effect. But although this ornament is often used, (and sometimes a still higher enriched moulding or band of open work flowers,) there are many doors of this style perfectly plain. Of this kind the door of Christchurch, Hants, is a fine specimen.

The dripstone is generally clearly marked, and often small, and supported by a head. In many doors, a trefoil and even cinquefoil feathering is used, the points of which generally finish with balls, roses, or some projecting ornament. The principal moulding of these doors has generally an equilateral arch, but from the depth and number of the mouldings, the exterior becomes often nearly a semi-circle. In interiors, and perhaps sometimes too in the exterior, there are instances of doors with a trefoil-headed arch. The shafts attached to these doors are generally round, but sometimes filleted, and they generally, but not always, stand quite free in a hollow moulding. They have a variety of capitals, many plain, but many with delicate leaves running up and curling round under the cap moulding, often looking like Ionic volutes. The bases are various, but a plain round and fillet is often used, and the reversed ogee sometimes introduced. All these mouldings are cut with great boldness, the hollows form fine deep shadows, and the rich bands of open-work leaves are as beautiful as at any subsequent period, being sometimes entirely hollow, and having no support but the attachment at the sides, and the connection of the leaves themselves. Of these doors, though they are not so numerous as the Norman, many still remain in perfect preservation; York, Lincoln, Chichester, and Salisbury, have extremely fine ones; and Beverley minster one, of which the mouldings are bolder than most of them. The door of the transept at York, and those of the choir screen at

Lincoln, have bands of the richest execution—and there is a fine double door at St. Cross.

There are many wooden doors, both of this style and the Norman, which seem to be of the same age as the stone work, and some very curiously ornamented with ramifications of iron-work from the hinges, &c.

Early English Windows.

These are, almost universally, long, narrow, and lancet-headed, generally without feathering, but in some instances trefoiled.

From this single shape of windows, a variety of appearance results from their combination. At Salisbury, one of the earliest complete buildings remaining, there are combinations of two, three, five, and seven. Where there are two there is often a trefoil, quatrefoil, &c. between the heads; and in large buildings, where there are three or more, they are often divided by so small a division as to seem the lights of a large window, but they are really separate windows, having their heads formed from individual centres, and in general separate dripstones. This is the case even at Westminster, where they approach nearer to a division by mullions, from having a small triangle pierced beside the quatrefoil, and a general dripstone over all. In small buildings, these are generally plain, with the slope of the opening considerable, and in some small chapels the windows are very narrow and long. In larger buildings they are often ornamented with very long and slender shafts, which are frequently banded. Most of our cathedrals contain traces of windows of this character, but some, as at Durham, have tracery added since their original erection. Salisbury, Chichester, Lincoln, Beverley, and York, still remain pure and beautiful; at York north transept are windows nearly fifty feet high, and about six or eight wide, which have a very fine effect. Although the architects of this style worked their ordinary windows thus plain, they bestowed much care on their circles. Beverley minster, York, Durham, and Lincoln, have all circles of this style peculiarly fine, and there may be many others; that of the south transept at York, usually called the marygold window, is extremely rich, but the tracery of the circles at Westminster is of a much later date.

There is in all the long windows of this style, one almost universal distinction; from the straight side of the window opening, if a shaft is added, it is mostly insular, and has seldom any connection with this side, so as to break it into faces, though the shafts are inserted into the sides of the doors, so as to give great variety to the opening.

At Westminster abbey, there are a series of windows above those of the aisles, which are formed in spherical equilateral triangles.

Early English Arches.

The window arch of this style being generally a lancet arch, and some persons having considered the shape of the arch to be a very distinguishing feature of the different styles, it may be necessary in this place to say a few words on arches generally. If we examine with care the various remains of the different styles, we shall see no such constancy of arch as has been apprehended; for there are composition lancet arches, used both at Henry the VII.'s chapel, Westminster, and at Bath; and there are flat segmental arches in the early English part of York; and upon the whole it will appear, that the architect was not confined to any particular description of arch. The only arch precisely attached to one period, is the four-centered arch, which does not appear in windows, &c. if it does in the composition of groins, before the perpendicular style. In large buildings, the nave arches of the early English style were often lancet, but in some large and many small ones, they are flatter, some of one-third drop, and perhaps even more, and sometimes pointed segmental.

At Canterbury, in the choir, are some curious pointed horse-shoe arches, and perhaps, though not common, they may be found in other places.

The architraves of the large arches of rich buildings are now beautifully moulded like the doors, with rich, deep, hollow mouldings, often enriched with the toothed ornament. Of this description, York transepts, and the nave and transepts of Lincoln, are beautiful specimens; Salisbury is worked plainer, but not less really beautiful, and Westminster abbey is (the nave at least) nearly plain, but with great boldness of moulding.

The arches of the gallery in this style, are often with trefoiled heads, and the mouldings running round the trefoil, even to the dripstone; Chester choir is a fine specimen, and there are some beautiful plain arches of this description in Winchester cathedral.

Early English Piers.

Of the piers of large buildings of this style, there are two distinguishing marks; first, the almost constant division of the shafts which compose them, by one or more bands in their length, and secondly, their being ranged circularly round the centre. In general they are few, sometimes only four, some-

times eight, set round a large circular one; such are the piers of Salisbury and of Westminster abbey; there are sometimes so many as nearly to hide the centre shaft, as at Lincoln and York; but the circular arrangement is still preserved, and there are some few, as at the choir at Chester, which come so near the appearance of decorated piers, as to be almost alone distinguishable by this circular arrangement.

The capitals of these shafts are various; in many, perhaps the greater number of buildings, they are plain, consisting of a bell with a single or double annulet under it, and a sort of coping, with more annulets above, and these mouldings are continued round the centre pier, so as to form a general capital. The dividing bands are also formed of annulets and fillets, and are often continued under windows, &c. as tablets, and are, like the capitals, continued round the centre shaft. Another and richer capital is sometimes used, which has leaves like those in the capitals of the door shafts. This kind of capital is generally used where the shafts entirely encompass the centre one, as at York and Lincoln, and has a very fine effect, the leaves being often very well executed. The bases used are frequently near approaches in contour to the Grecian attic base, but the reversed ogee is sometimes used. There is another sort of pier in buildings that appear to be of this style, which is at times very confusing, as the same kind of pier seems to be used in small churches even to a very late date; this is the plain multangular (generally octagonal) pier with a plain capital, of a few very simple mouldings, and with a plain sloped arch. Piers of this description are very frequent, and it requires great nicety of observation and discrimination to refer them to their proper date; but a minute examination will often, by some small matter, detect their age, though it is impossible to describe the minutiæ without many figures.

Early English Buttresses.

These are of four descriptions. 1st, The old Norman flat buttress is often used, but it is not always as broad, and its tablets, &c. are more delicate.

2nd, A buttress not so broad as the flat one, but nearly of the same projection as breadth, and carried up, sometimes with only one set-off, and sometimes without any, and these have often their edges chamfered from the window tablet. They sometimes have a shaft at the corner, and in large rich buildings are occasionally pannelled.

3d, A long slender buttress, of narrow face, and great projection in few stages, is used in some towers, but is not very common.

4th, Towards the latter part of this style, the buttress in stages was used, but it is not very common, and is sufficiently distinguished by its triangular head, the usual finish of this style, which can hardly be called a pinnacle, though sometimes it slopes off from the front to a point.

Early English Tablets.

The cornice is now become sometimes rich in mouldings, and often with an upper slope, making the face of the parapet perpendicular to the wall below; there are cornices of this style still resembling the Norman projecting parapet, but they consist of several mouldings. The hollow moulding of the cornice is generally plain, seldom containing flowers or carvings, but under the mouldings there is often a series of small arches resembling the corbel table.

The dripstone of this style is various, sometimes of several mouldings, sometimes only a round with a small hollow. It is, in the interior, occasionally ornamented with the toothed ornament, and in a few late instances, as the interior of the choir at Westminster, with flowers. In a few buildings, the dripstone is returned, and runs as a tablet along the walls. It is in general narrow, and generally supported by a corbel, either of a head or a flower, &c. There are frequently, in large buildings, in the ornamented parts, bands of trefoils, quatrefoils, &c. some of them very rich. Although a sort of straight canopy is used over some of the niches of this style, yet it does not appear to have been used over windows or doors. In some few buildings where they are found, they appear to be additions. The tablets forming the base mouldings are sometimes a mere slope, at others, in large buildings, are of several sets of mouldings, each face projecting farther than the one above it; but the reversed ogee is very seldom used, at least at large and singly.

Early English Niches.

The most important niches are those found in chancels, in the walls of the south side, and of which the uses do not yet appear to be decided. Of these there are many of all stages of Early English; there are sometimes two, but oftener three, and they are generally sunk in the wall, and adapted for a seat, the easternmost one often higher in the seat than the others. They are sometimes a plain trefoil head, and sometimes ornamented with shafts, &c.; they are generally straight-sided. The statuary niches, and ornamental interior niches, mostly consist of a series of arches, some of them slope-sided, and some with a small but not very visible pedestal for the statu

They are often grouped two under one arch, with an ornamental opening between the small arches, and the large one like the double doors; a straight-sided canopy is sometimes used, and a plain finial. These niches, except the chancel stalls, and the stoup and piscina, are seldom single, except in buttresses, but mostly in ranges.

Early English Ornaments.

The first ornament to be described, is that already noticed as the peculiar distinction of this style, to which it seems nearly, if not exclusively confined; it is the regular progression from the Norman zigzag to the delicate four-leaved flowers so common in Decorated English buildings. Like the zigzag it is generally straight-sided, and not round like the leaves of a flower, though, at a distance in front, it looks much like a small flower. It is very difficult to describe it, and still more so to draw it accurately; it may perhaps be understood by considering it a succession of small open pyramids of four legs, which are formed of half a cube, and set on the edges of a hollow moulding. This ornament is used very profusely in the buildings of this style, in Yorkshire and Lincolnshire, and frequently in those of other counties.

Another ornament, which, though not peculiar, in small works, to this style, was seldom but during its continuance practised to so large an extent; this is the filling of the spaces above the choir arches with squares, enclosing four-leaved flowers. This is done at Westminster and at Chichester, in both of which the workmanship is extremely good, and it has a very rich effect.

In many parts, as in the spandrells of door arches, and other plain spaces, circles filled with trefoils and quatrefoils, with flowered points, are often introduced. In the early part of the style, crockets were not used, and the finial was a plain bunch of three or more leaves, or sometimes only a sort of knob; but in small rich works, towards the end of the style, the beautiful finials and crockets of the next style were used.

Early English Steeples.

The Norman towers were short and thick, the Early English rose to a much greater height, and on the tower they placed that beautiful addition the spire.

Some of our finest spires are of this age, and the proportions observed between the tower and spire, are generally very good. Salisbury, which stands unrivalled in height and beauty, and Chichester, are of this age, as are the towers of Lincoln minster. Wakefield has a fine steeple, as to proportion, though plain, and

it is singular for its machicolations, in the top of the tower. The towers are flanked by octagonal turrets, square flat buttresses, or, in a few instances, with small long buttresses, and generally there is one large octagonal pinnacle at the corners, or a collection of smaller niches, &c. There often is no parapet, but the slope of the spire runs down to the edge of the wall of the tower, and finishes there with a tablet; and there is a double slope to connect the corners with the intermediate faces. The spire is often ornamented by ribs at the angles, sometimes with crockets on the ribs, and bands of squares, filled with quatrefoils, &c. surrounding the spire at different heights. There are many good spires of this style in country churches.

Of this style we have the great advantage of one building remaining, worked in its best manner, of great size and in excellent preservation; this is Salisbury, which cathedral gives a very high idea of improvement on the Norman style: magnificent without rudeness, and rich though simple, it is one uniform whole. The west front is ornamented, but by no means loaded, and the appearance of the north side is perhaps equal to that of any cathedral in England. The west front of Lincoln is fine, but the old Norman space is too visible not to break it into parts. Peterborough and Ely have perhaps the most ornamented fronts of this style. Westminster is spoiled by additions, but its north transept end is fine, as are both the transepts of York. Interiorly, after the simple Salisbury, the transepts of York are perhaps the best specimens, though there are parts of many other buildings deserving much attention.

Not much has been done in either restoring or imitating this style; it is certainly not easy to do either well, but it deserves attention, as in many places it would be peculiarly appropriate, and perhaps is better fitted than any for small country churches. It may be worked almost entirely plain, yet if ornament is used, it should be well executed; for the ornaments of this style are in general as well executed as any of later date, and the toothed ornament and hollow bands equal, in difficulty of execution, the most elaborate perpendicular ornaments.

Of the Third, or Decorated English Style

Decorated English Doors.

The large doors of the last style are mostly double, and there are some fine ones of this, but they are not so common, there being more single doors, which are often nearly as large as the Early English double ones, and indeed but for the ornaments they are much alike, having shafts and fine hollow

mouldings; in small doors there are often no shafts at all, but the arch mouldings run down the side, and often almost to the ground without a base. The shafts do not in this style generally stand free, but are parts of the sweep of mouldings, and instead of being cut and set up lengthways, all the mouldings and shafts are cut on the arch stone, thus combining great strength with all the appearance of lightness. The capitals of these shafts differ from the Early English, in being formed of a woven foliage, and not upright leaves; this, in small shafts, generally has an apparent neck, but in larger ones often appears like a round ball of open foliage. The bases to these shafts mostly consist of the reversed ogee, but other mouldings are often added, and the ogee often made in faces. Although the doors in general are not so deeply recessed, as the Norman and Early English, yet in many large buildings they are very deep. The west doors of York, and the later west doors of Beverley, are of the richest execution, and very deep. To the open work bands of the last style, succeeds an ornament equally beautiful, and not so fragile; this is the flowery hollow moulding; there are often three or four in one door-way, and to the toothed ornament succeeds a flower of four leaves, in a deep moulding, with considerable intervals between. This flower, in some buildings, is used in great profusion to good effect, and a perforated ball in other buildings in equal abundance. Over these doors, there are several sorts of canopies; the dripstone is generally supported by a corbel, which is commonly a head; in some instances a plain return is used, but that return seldom runs horizontally. The canopy is sometimes connected with the dripstone, and sometimes distinct. The common canopy is a triangle, the space between it and the dripstone is filled with tracery, and the exterior ornamented with crockets, and crowned with a finial. On the side of the doors, small buttresses or niches are sometimes placed. The second canopy is the ogee, which runs about half up the dripstone, and then is turned the contrary way, and is finished in a straight line running up into a finial. This has its intermediate space filled with tracery, &c. and is sometimes crocketed and sometimes not. Another sort of canopy is an arch running over the door, and unconnected with it, which is doubly foliated; it has a good effect, but is not common.

In small churches, there are often nearly plain doors, having only a dripstone and a round moulding on the interior edge, and the rest of the wall a straight line or bold hollow, and in some instances a straight slope side only. In some doors of this style, a series of niches with statues are carried up like a hollow moulding; and in others, doubly foliated

tracery hanging free from one of the outer mouldings, give a richness superior to any other decoration. The south door of the choir at Lincoln is perhaps hardly any where equalled of the first kind; and the west doors at Beverley are good illustrations of the other.

Decorated English Windows.

In these the clearest marks of the style are to be found, and they are very various, yet all on one principle: an arch is divided by one or more mullions, into two or more lights, and these mullions branch into tracery of various figures, but do not run in perpendicular lines through the head. In small churches, windows of two or three lights are common, but in larger four and five lights for the aisles and clerestory windows, five or six for transepts and the end of aisles, and in the east and west windows seven, eight, and even nine lights, are used. Nine lights seem to be the extent, but there may be windows of this style containing more. The west window of York, and the east window of Lincoln cathedrals, are of eight lights each; the west window of Exeter cathedral is of nine, and these are nearly, if not quite, the largest windows remaining.

There may be observed two descriptions of tracery, and although, in different parts, they may have been worked at the same time, yet the first is generally the oldest. In this first division, the figures, such as circles, trefoils, quatrefoils, &c. are all worked with the same moulding, and sometimes do not regularly join each other, but touch only at points. This may be called geometrical tracery; of this description are the windows of the nave of York, the eastern choir of Lincoln, and some of the tracery in the cloisters at Westminster abbey, as well as most of the windows at Exeter, which contains, perhaps, the richest variety of windows of any cathedral in England, and some of them are of such admirable workmanship as to almost belong to the second division.

The second division consists of what may be truly called *flowing* tracery. Of this description, York minster, the minster, and St. Mary's, at Beverley, Newark church, and many northern churches, as well some southern churches, contain most beautiful specimens. The one engraved is from the west end of the south aisle of Newark, and is perhaps one of the most beautiful in its composition. The great west window at York is, perhaps, the most elaborate. In these windows, various wheels are sometimes introduced. In the richer windows of this style, and in both divisions, the principal moulding of the mullion has sometimes a capital and base,

and thus becomes a shaft. One great cause of the beauty of fine flowing tracery, is the intricacy and delicacy of the mouldings; the principal moulding often running up only one or two mullions, and forming only a part of the larger design, and all the small figures being formed in mouldings, which spring from the sides of the principal. This is a distinction the plate was too small to admit, which takes much from the beauty of the window. The architraves of windows of this style are now much ornamented with mouldings, which are sometimes made into shafts. The dripstones and canopies of windows are the same as in the doors, and have been described under that head. Wherever windows of this style remain, an artist should copy them; the varieties are much greater than might be supposed, for it is very difficult to find two alike in different buildings.

It does not appear that the straight horizontal transom was much if at all used in windows of this style; wherever it is found there is generally some mark of the window originating after the introduction of the perpendicular style; but it may have been used in some places, and there are a very few instances of a light being divided in height by a kind of canopy, or a quatrefoil breaking the mullion; the church of Dorchester, in Oxfordshire, has some very curious windows of this kind. In some counties, where flint and chalk are used, the dripstone is sometimes omitted. The heads of the windows of this style are most commonly the equilateral arch; though there are many examples both of lancet and drop arches; but the lancet arches are not very sharp, perhaps never exceeding one-third of the equilateral. There are a few windows of this style with square heads; but they are not very common.

The circles of this style are some of them very fine; there are some very good ones in composition at Exeter and Chichester, and the east window of old St. Paul's was a very fine one; but perhaps the richest remaining is that of the south transept at Lincoln, which is completely flowing.

Towards the end of this style, and perhaps after the commencement of the next, we find windows of most beautiful composition, with parts like the perpendicular windows, and sometimes a building has one end decorated, the other perpendicular: such is Melrose abbey, whose windows have been extremely fine, and, indeed, the great east window of York, which is the finest perpendicular window in England, has still some traces of flowing lines in its head.

Decorated English Arches.

Though the arch most commonly used for general purposes in this style is the equilateral one, yet this is by no means constant. At York this arch is used, but at Ely a drop arch. The architrave mouldings of interior arches do not differ much from those of the last style, except that they are, perhaps, more frequently continued down the pier without being stopt at the line of capitals. The dripstones are of delicate mouldings, generally supported by heads. The arches of the galleries are often beautifully ornamented with foliated heads, and often fine canopies; and in these arches the ogee arch is sometimes used, as it is freely in composition in the heads of windows.

Of this style, or perhaps of the next, is that singular yet beautiful reversed arch in the nave of Wells' cathedral.

Decorated English Piers.

A new disposition of shafts marks very decidedly this style in large buildings, they being arranged diamondwise, with straight sides, often containing as many shafts as will stand close to each other at the capital, and only a fillet or small hollow between them. The shaft which runs up to support the roof, often springs from a rich corbel between the outer architrave mouldings of the arches; Exeter is a fine example. The capitals and bases of these shafts are much the same as those decribed in the section on doors. Another pier of the richest effect, but seldom executed, is that at York minster, where the centre shaft is larger than those on each side, and the three all run through the spring of the roof. Three also support the side of the arch; these shafts are larger in proportion than those of Exeter, &c. and stand close without any moulding between.

Another pier, common towards the end of this style, and the beginning of the next, is composed of four shafts, about two-fifths engaged, and a fillet and bold hollow half as large as the shafts between each; this makes a very light and beautiful pier, and is much used in smaller churches. All these kinds of piers have their shafts sometimes filleted, as are also often some of the architrave mouldings. In small country churches, the multangular flat-faced pier seems to have been used.

Decorated English Buttresses.

These, though very various, are all more or less worked in stages, and the set-off's variously ornamented, some plain, some moulded slopes, some with triangular heads, and some with pannels; some with niches in them, and with all the

various degrees of ornament. The corner buttresses of this style are often set diagonally. In some few instances small turrets are used as buttresses. The buttresses are variously finished, some slope under the cornice, some just through it; some run up through the battlement, and are finished with pinnacles of various kinds.

Decorated English Tablets.

The cornice is very regular, and though in some large buildings it has several mouldings, it principally consists of a slope above, and a deep sunk hollow, with an astragal under it; in these hollows, flowers at regular distances are often placed, and in some large buildings, and in towers, &c. there are frequently heads, and the cornice almost filled with them. The dripstone is of the same description of mouldings, but smaller, and this too is sometimes enriched with flowers. The small tablet running under the window has nearly the same mouldings, but mostly without the astragal, and this sometimes runs round the buttress also. The dripstone very seldom, if ever, runs horizontally, though in a few instances a return is used instead of the more common corbel head or shield.

The basement tablets are sometimes numerous, and often have the reversed ogee repeated.

Decorated English Niches.

These form one of the greatest beauties of the style, and are very various, but may be divided into two grand divisions, which, if necessary, might be again variously divided, such is their diversity, but these two may be sufficient. The first are pannelled niches, the fronts of whose canopies are even with the face of the wall or buttress they are set in. These have their interiors either square with a sloping side, or are regular semi-hexagons, &c. In the first case, if not very deep, the roof is a plain arch, but in the latter case the roof is often most delicately groined, and sometimes a little shaft is set in the angles or the ribs of the roof, supported by small corbels. The pedestals are often high and much ornamented.

The other division of niches have projecting canopies; these are of various shapes, some conical like a spire, some like several triangular canopies joined at the edges, and some with ogee heads; and in some very rich buildings are niches with the canopy bending forwards in a slight ogee, as well as its contour being ogee; these are generally crowned with very large rich finials, and very highly enriched. There were also, at the latter part of this style, some instances of the niche with

a flat-headed canopy, which became so common in the next style. These projecting niches have all some projecting base, either a large corbel, or a basement pedestal carried up from the next projecting face below. All these niches are occasionally flanked by small buttresses, and their pinnacles; those of the first kind have very often beautiful shafts.

The chancel stalls of this style, are many of them uncommonly rich, their whole faces being often covered with ornamental carving

Decorated English Ornaments.

As the word decorated is used to designate this style, and particularly as the next is often called florid, as if it were richer in ornament than this, it will be necessary to state, that though ornament is often profusely used in this style, yet these ornaments are like Grecian enrichments, and may be left out without destroying the grand design of the building, while the ornaments of the next are more often a minute division of parts of the building, as pannels, buttresses, &c. rather than the carved ornaments used in this style. In some of the more magnificent works, a variety of flowered carvings are used all over, and yet the building does not appear overloaded; while some of the later perpendicular buildings have much less flowered carvings, yet look overloaded with ornaments, from the fatiguing recurrence of minute parts, which prevent the general design being comprehended.

The tomb of the Percys at Beverley, and one or two at York, are as rich as can well be conceived in ornamental carvings, yet the general design is noble, and may be clearly understood, while the design of Henry the VII.'s chapel can hardly be comprehended, from the constant repetition of the same ornaments, which, if worked singly, are not very rich.

The flower of four leaves in a hollow moulding, has already been spoken of, and in these hollow mouldings various other flowers are introduced, as well as heads and figures, some of them very grotesque; and as to capitals, there are very seldom found two alike. The foliage forming the crockets and finials is also extremely rich, and the pinnacle, in its various forms, is almost constantly used. The spandrells of ornamental arches are sometimes filled with beautiful foliage, perhaps few superior to some in the church at Ely, which was the lady chapel of the cathedral.

Decorated English Steeples.

Of this style are many of these beautiful ornaments of the

country; at the commencement of it, several fine spires were added to towers then existing, and in after times many very fine towers and spires were erected. Grantham and several other Lincolnshire spires are very fine, and there are many good towers. These are generally flanked with buttresses, many of which are diagonal, and are generally crowned with fine pinnacles. Perhaps the church of St. Michael, at Coventry, is as elegant a spire and tower as any of this age, and is curious, from the spire standing on a lantern above the tower. In Lincolnshire and some of the adjoining counties, there are many village churches with fine spires, and some of this style; of these, perhaps few, if any, exceed in beauty of proportion and delicacy of composition that of Norton, a village in Leicestershire, a few miles to the left of the road from Uppingham to Leicester. The singular crowned steeple of St. Nicholas, at Newcastle upon Tyne, is either of this style or early in the next.

There are many of the towers of this age whose windows, or at least the mullions, seem to have been renewed in the perpendicular style, and indeed, in small churches, it is not always easy precisely to fix the style of the tower because of these alterations.

Although they have some appearances of the windows which belong to the next style, yet to this age should be referred the towers of York minster, which possess uncommon beauty.

Though we have not the advantage of any one large building of this style in its pure state, like Salisbury, yet we have the advantage of four most beautiful models, which are in the highest preservation, besides many detached parts. These are at Lincoln, Exeter, York, and Ely, and though differently worked, are all of excellent execution. Of these, Exeter and York are far the largest, and York, from the uncommon grandeur and simplicity of the design, is certainly the finest; ornament is no where spared, yet there is a simplicity which is peculiarly pleasing. Amongst the many smaller churches, Trinity church at Hull deserves peculiar notice, as its decorated part is of a character which could better than any be imitated in modern work, from the great height of its piers, and the smallness of their size. The remains of Melrose abbey are extremely rich, and, though in ruins, its parts are yet very distinguishable. In imitations of this style, great delicacy is required to prevent its running into the next, which, from its straight perpendicular and horizontal lines, is so much easier worked; whatever ornaments are used, should be very cleanly executed, and highly finished.

Of the Fourth, or Perpendicular Style.

Perpendicular English Doors.

An impression from an engraving of a perpendicular door having been given on the cover of several numbers of this work, our readers must, by this time, be well acquainted with it. A copy is annexed, for the purpose of permanent reference, with the other plates. It has been drawn to convey as distinct an idea as possible of the character of the generality of these doors, the great distinction of which, from those of the last style, is the almost constant square head over the arch, which is surrounded by the outer moulding of the architrave, and the spandrell filled with some ornament, and over all a dripstone is generally placed. This ornamented spandrell in a square head, occurs in the porch to Westminster Hall, one of the earliest perpendicular buildings, and is continued to the latest period of good execution, and in a rough way much later. In large very rich doors, a canopy is sometimes included in this square head, and sometimes niches are added at the sides, as at King's college chapel, Cambridge. This square head is not always used interiorly, for an ogee canopy is sometimes used, or pannels down to the arch, as at St. George's, Windsor; and there may be some small exterior side doors, without the square head, but they are not common. The shafts used in these doors are small, and have plain capitals, which are often octagonal, and the bases made so below the first astragal. It is also very common for the architrave to consist of ogee mouldings, as well as the rounds and hollows which have been before used.

Perpendicular English Windows.

These are easily distinguished by their mullions running in perpendicular lines, and the transoms, which are now general. The varieties of the last style were in the disposition of the principal lines of the tracery; in this, they are rather in the disposition of the minute parts, a window of four or more lights is generally divided into two or three parts by stronger mullions running quite up, and the portion of arch between them doubled, from the centre of the side division. In large windows, the centre one is again sometimes made an arch, and often in windows of seven or nine lights, the arches spring across, making two of four or five lights, and the centre belonging to each. The heads of windows, instead of being filled with flowing ramifications, have slender mullions running from the heads of the lights, between each principal mullion, and these have small transoms till the window is divided into

a series of small pannels; and the heads being arched, are trefoiled or cinquefoiled; sometimes these small mullions are crossed over each other in small arches, leaving minute quatrefoils, and these are carried across in straight lines. Under the transom is generally an arch of some kind, but in Yorkshire, Lincolnshire, and Nottinghamshire, and perhaps in some other parts, there is a different mode of foliating the straight line without an arch, which has a singular appearance, (see plate I.) In the later windows of this style, the transoms are often ornamented with small battlements, which, when well executed, have a very fine effect. Amidst so great a variety of windows, (for perhaps full half the windows in English edifices over the kingdom are of this style,) it is difficult which to notice; but Windsor, St. George's, for four lights, and the clerestory windows of Henry the VII.'s chapel for five, are some of the best executed; for a large window, the east window of York has no equal, and by taking its parts, almost any sized window may be formed. There are some good windows, of which the heads have the mullions alternate, that is, the perpendicular line rises from the top of the arch of the pannel below it. The windows of the Abbey church, at Bath, are of this description.

It is necessary here to say a little of a window which may be mistaken for a decorated window: this is one of three lights, used in many country churches, the mullions simply cross each other, and are cinquefoiled in the heads, and quatrefoiled in the three upper spaces; but to distinguish this from a decorated window, it will generally be necessary to examine its arch, its mullion mouldings, and its dripstone, as well as its being (as it often is) accompanied by a clearly perpendicular window at the end, or connected with it so as to be evidently of that time. Its arch is very often four-centred, which at once decides its date; its mullion mouldings are often small, and very delicately worked; its dripstone often has some clear mark, and when the decorated tracery is become familiar, it will be distinguished by its being a mere foliation of a space, and not a flowing quatrefoil with the mouldings carried round it.

Large circular windows do not appear to have been in use in this style; but the tracery of the circles in the transepts of Westminster abbey appear to have been renewed during this period. At Henry the VII.'s chapel, a window is used in the aisles, which seem to have led the way to that wretched substitute for fine tracery, the square-headed windows of queen Elizabeth and king James the First's time. This window is a series of small pannels forming a square head, and it is not flat, but in projections, and these, with the octagonal towers used

for buttresses, throw the exterior of the building into fritter, ill-assorting with the richness of the clerestory windows. In most of the later buildings of this style, the window and its architrave completely fills up the space between the buttresses, and the east and west windows are often very large; the west window of St. George's, Windsor, has fifteen lights in three divisions, and is a grand series of pannels, from the floor to the roof; the door is amongst the lower ones, and all above the next to the door is pierced for the window. The east window at Gloucester is also very large, but that is of three distinct parts, not in the same line of plan.

When canopies are used, which is not so often as in the last style, they are generally of the ogee character, beautifully crocketed.

Perpendicular English Arches.

Although the four-centred arch is much used, particularly in the latter part of the style, yet, as in all the other styles, we have in this also arches of almost all sorts amongst the ornamental parts of niches, &c. and in the composition lines of pannels, are arches from a very fine thin lancet to an almost flat segment. Yet, with all this variety, the four-centred arch is the one most used in large buildings, and the arches of other characters, used in the division of the aisles, begin to have what is one of the great distinctions of this style,—the almost constant use of mouldings running from the base all round the arch, without any stop horizontally, by way of capital, sometimes with one shaft and capital, and the rest of the lines running. The shafts in front running up without stop to the roof, and from their capitals springing the groins. In window arches, shafts are now very seldom used, the architrave running all round, and both window arches and the arches of the interior are often enclosed in squares, with ornamented spandrels, either like the doors, or of pannelling. Interior arches have now seldom any dripstone when the square is used, but at Bath there is a clear dripstone distinct from the arch mouldings.

Another great distinction of these arches, in large buildings, is the absence of the triforium or gallery, between the arches of the nave and the clerestory windows; their place is now supplied by pannels, as at St. George's, Windsor, or statuary niches, as at Henry the VII.'s chapel; or they are entirely removed, as at Bath, and Manchester Old church, &c.

Perpendicular English Piers.

The massive Norman round pier, lessened in size and extended in length, with shafts set round it, became the Early Eng-

lish pier; the shafts were multiplied and set into the face of the pier, which became, in its plan, lozenge, and formed the decorated pier; we now find the pier again altering in shape, becoming much thinner between the arches, and its proportion the other way, from the nave to the aisle, increased by having those shafts which run to the roof, to support the springings of the groins, added in front, and not forming a part of the mouldings of the arch, but having a bold hollow between them: this is particularly apparent at King's college chapel, Cambridge, St. George's, Windsor, and Henry the VII.'s chapel, the three great models of enriched perpendicular style; but it is observable in a less degree in many others. In small churches, the pier mentioned in the last style, of four shafts and four hollows, is still much used; but many small churches have humble imitations of the magnificent arrangement of shafts and mouldings spoken of above. There are still some plain octagonal, &c. piers, in small churches, which may belong to this age.

Though filleted shafts are not so much used as in the last style, the exterior moulding of the architrave of interior arches is sometimes a filleted round, which has a good effect; and in general the mouldings and parts of piers, architraves, &c. are much smaller than those used in the last style.

Perpendicular English Buttresses.

These differ very little from those of the last style, except that triangular heads to the stages are much less used, the set-off's being much more often bold projections of plain slopes; yet many fine buildings have the triangular heads. In the upper story, the buttresses are often very thin, and of diagonal faces. There are few large buildings of this style without flying buttresses, and these are often pierced; at Henry VII.'s chapel they are of rich tracery, and the buttresses are octagonal turrets. At King's college chapel, Cambridge, which has only one height within, the projection of the buttresses is so great as to allow chapels between the wall of the nave and another level with the front of the buttresses. At Gloucester, and perhaps at some other places, an arch or half arch is pierced in the lower part of the buttress There are a few buildings of this style without any buttresses. All the kinds are occasionally ornamented with statuary niches, and canopies of various descriptions, and the diagonal corner buttress is not so common as in the last style; but the two buttresses often leave a square, which runs up, and sometimes, as at the tower of the Old church at Manchester, is crowned with a third pinnacle.

Although pinnacles are used very freely in this style, yet

there are some buildings whose buttresses run up and finish square without any; of this description is St. George's, Windsor. The buttresses of the small eastern addition at Peterborough cathedral are curious, having statues of saints for pinnacles.

In interior ornaments, the buttresses used are sometimes small octagons, sometimes pannelled, sometimes plain, and then, as well as the small buttresses of niches, are often banded with a band different from the Early English, and much broader. Such are the buttresses between the doors of Henry the VII.'s chapel.

Perpendicular English Tablets.

The cornice is now, in large buildings, often composed of many small mouldings, sometimes divided by one or two considerable hollows, not very deep; yet still, in plain buildings, the old cornice mouldings are much adhered to; but it is oftener ornamented in the hollow with flowers, &c. and sometimes with grotesque animals; of this the churches of Gresford and Mold, in Flintshire, are curious examples, being a complete chase of cats, rats, mice, dogs, and a variety of imaginary figures, amongst which various grotesque monkeys are very conspicuous. In the latter end of the style, something very analogous to an ornamented frieze is perceived, of which the canopies to the niches, in various works, are examples; and the angels so profusely introduced, in the later rich works, are a sort of cornice ornaments. These are very conspicuous at St. George's, Windsor, and Henry the VII.'s chapel. At Bath is a cornice of two hollows, and a round between with fillets, both upper and under surface alike. The dripstone of this style is, in the heads of doors and some windows, much the same as in the last style, and it most generally finishes by a plain return; though corbels are sometimes used, this return is frequently continued horizontally. Sometimes a much smaller dripstone is used, of only a round and hollow.

Tablets under the windows are like this last or other dripstone, and sometimes fine bands are carried round as tablets. Of these there are some fine remains at the cathedral, and at the tower of St John's, Chester.

The basement mouldings ordinarily used are not materially different from the last style; reversed ogees and hollows, variously disposed, being the principal mouldings.

Perpendicular English Niches.

These are very numerous, as amongst them we must include nearly all the stall, tabernacle, and screen work, in the English

churches; for there appears little if any wood-work of an older date, and it is probable that much screen work was defaced at the reformation, and restored in queen Mary's time, and not again destroyed, at least the execution of much of it would lead to such a supposition, being very full of minute tracery, and much attempt at stiffly ornamented friezes. Many niches are simple recesses, with rich ogee canopies, and others have overhanging square-headed canopies, with many minute buttresses and pinnacles, crowned with battlements; or, in the latter part of the style, with what has been called the Tudor flower, an ornament used instead of battlement, as an upper finish, and profusely strewed over the roofs, &c. of the richer later buildings. Of these niches, those in Henry the VII.'s chapel, between the arches and clerestory windows, are perhaps as good a specimen as any. Of the plain recesses, with ogee canopies, there are some fine ones at Windsor.

The whole interior of the richer buildings of this style, is more or less a series of pannels, and therefore, as every pannel may, on occasion, become a niche, we find great variety of shape and size; but like those of the last style, they may generally be reduced to one or other of these divisions.

Perpendicular English Ornaments.

The grand source of ornament, in this style, is pannelling, indeed, the interior of most rich buildings is only a general series of it; for example, King's college chapel, Cambridge, is all pannel except the floor; for the doors and windows are nothing but pierced pannels included in the general design, and the very roof is a series of them of different shapes. The same may be said of the interior of St. George's, Windsor, and still further, Henry the VII.'s chapel is so both within and without, there being no plain wall all over the chapel, except just the exterior below the base moulding, all above is ornamental pannel. All the small chapels of late erection, in this style, such as those of Bishop Fox at Winchester, and several in Windsor, are thus all pierced pannel. Exclusive of this general source of ornament, there are a few peculiar to it: one, the battlement to transoms of windows, has already been mentioned; this, in works of late date, is very frequent, sometimes extending to small transoms in the head of the window, as well as the general division of the lights. Another, the Tudor flower, is, in rich work, equally common, and forms a most beautiful enriched battlement, and is also sometimes used on the transoms of windows in small work. Another peculiar ornament of this style, is the angel cornice, used at Windsor and Henry the VII.'s chapel; but though according

with the character of those buildings, it is by no means fit for general use. These angels have been much diffused, as supporters of shields, and as corbels to support roof beams, &c. Plain as the Abbey-church at Bath is in its general execution, it has a variety of angels as corbels, for different purposes.

Flowers of various kinds continue to ornament cornices, &c. and crockets were variously formed towards the end of the style, those of pinnacles were often very much projected, which has a disagreeable effect; there are many of these pinnacles at Oxford, principally worked in the decline of the style.

Perpendicular English Steeples.

Of these there remain specimens of almost every description, from the plain short tower of a country church, to the elaborate and gorgeous towers of Gloucester and Wrexham. There are various fine spires of this style, which have little distinction from those of the last, but their age may be generally known by their ornaments, or the towers supporting them. Almost every conceivable variation of buttress, battlement, and pinnacle, is used, and the appearance of many of the towers combines, in a very eminent degree, extraordinary richness of execution and grandeur of design. Few counties in England are without some good examples; besides the two already mentioned, Boston in Lincolnshire, All-Saints in Derby, St. Mary's at Taunton, St. George's, Doncaster, are celebrated; and the plain, but excellently proportioned, tower of Magdalen college, Oxford, deserves much attention.

Amongst the smaller churches, there are many towers of uncommon beauty, but few exceed Gresford, between Chester and Wrexham; indeed, the whole of this church, both interior and exterior, is worth attentive examination. Paunton, near Grantham, has also a tower curious for its excellent masonry. There are of this style some small churches with fine octagonal lanterns, of which description are two in the city of York.

Miscellaneous Remarks on Perpendicular Buildings.

Of this style are so many buildings in the finest preservation, that it is difficult to select; but, on various accounts, several claim particular mention. The choir at York is one of the earliest buildings; indeed it is, in general arrangements, like the nave, but its ornamental parts, the gallery under the windows, the windows themselves, and much of its pannelling in the interior, are completely of perpendicular character, though the simple nobility of the piers is the same as the

nave. The choir of Gloucester is also of this style, and most completely so, for the whole interior is one series of open-work pannels laid on the Norman work, parts of which are cut away to receive them; it forms a very ornamental whole, but by no means a model for imitation.

Of the later character, are three most beautiful specimens, King's college chapel, Cambridge, Henry the VII.'s chapel, and St. George's, Windsor; in these, richness of ornament is lavished on every part, and they are particularly valuable for being extremely different from each other, though in many respects alike. Of these, undoubtedly St. George's, Windsor, is the most valuable, from the great variety of composition arising from its plan; but the roof and single line of wall, of King's college chapel, Cambridge, deserves great attention, and the details of Henry the VII.'s chapel will always command it, from the great delicacy of their execution.

Of small churches, there are many excellent models for imitation, so that in this style, with some care and examination, nothing hardly need be executed but from absolute authority. The monumental chapels of this style are peculiarly deserving attention, and often of the most elaborate workmanship.

Of Battlements.

Having now gone through the styles in detail, we come to those sections which, as before mentioned, it is necessary to give in a connected series.

From exposure to weather and various accidents, we find very few roofs in their original state, and from the vicinity of the battlement, &c. we find these also are very often not original. It seems difficult to ascertain what the Norman battlement was, and there seems much reason to suppose it was only a plain parapet; many Norman structures have either battlements evidently of later date, or parapets as evidently mutilated, and in the larger buildings of the early English style, the parapet continues mostly to be used. Perhaps some of the earliest battlement is that at the west end of Salisbury cathedral, plain, of nearly equal intervals, and with a plain capping moulding; but it may be doubted if even this is original. An ornamented parapet continued to be used through the next style, but with the very frequent use of battlements of several sorts, both plain and pierced; and as these continued with less alteration than many other parts, through the perpendicular style, it will be better to describe them all together, just observing, that a considerable degree of perpendicular pannelling prevails in the battlements of the later edifices. The most frequent early

pierced parapet, is a series of interchanged trefoils with a fine serpentine line separating them; this has a fine effect, and is mostly used in Decorated English buildings; for in the Perpendicular, the dividing line is straight, making a series of interchanged triangles. Of pierced battlements there are many varieties, but the early ones have frequently quatrefoils, either for the lower compartments, or on the top of the pannels of the lower, to form the higher; the latter have often two heights of pannels, one range for the lower, and another over them forming the upper; and at Loughborough is a fine battlement of rich pierced quatrefoils, in two heights, forming an indented battlement. These battlements have generally a running cap moulding carried round, and generally following the line of battlement. There are some few later buildings, which have pierced battlements, not with straight tops, but variously ornamented; such is the tomb house at Windsor, with pointed upper compartments, and such is the battlement of the eastern addition at Peterborough, and the great battlement of King's college chapel, Cambridge, and also that most delicate battlement over the lower side chapels; this is perhaps the most elegant of the kind. Sometimes exteriorly, and often interiorly, the Tudor flower is used as a battlement, and there are a few instances of the use of a battlement analogous to it in small works long before; such is that at Waltham cross.

Of plain battlements there are several descriptions: 1st, that of nearly equal intervals, with a plain round capping running round with the outline. 2nd, The castellated battlement, of nearly equal intervals, and sometimes with large battlements and small intervals, with the cap moulding running only horizontal, and the sides cut plain; this is perhaps the best in point of effect of any. 3d, A battlement like the last, with the addition of a moulding which runs round the outline, and has the horizontal capping set upon it. 4th, The most common later battlement, with the cap moulding broad, of several mouldings, and running round the outline, and thus often narrowing the intervals, and enlarging the battlement. To one or other of these varieties, most battlements may be reduced; but they are never to be depended on alone, in determining the age of a building, from the very frequent alteration they are liable to.

Of Roofs.

Roofs may be conveniently divided into two principal divisions; the first including those in which the sloped framing, carrying the lead or other covering, is visible; and the second, those which have an inner roof of various materials.

English roofs.

It is difficult to say what were the open Norman roofs, but it seems most likely they exposed the rafters and other framing of the roof, and probably had straight beams laid across the walls of the nave over each pier. If any original roofs of this kind remain, Rochester cathedral seems most likely to be one. The first attempt to ornament these roofs, seems to have been to make a timber arch over each pier, and to frame timbers in squares diagonally, and these are sometimes made into quatrefoils, and afterwards the arch framing became variously ornamented, till it came to the gorgeous hall roof, of which there are many fine specimens, but perhaps few, if any, superior to that of Westminster hall. The roof of St. Stephen's chapel was of peculiar beauty, and that of the chapter-house at Exeter, is much like it. From the piers, springs an arch which is pierced in the spandrells, and richly ornamented with pierced featherings; and the sloping roof is constructed in small squares, beautifully ornamented with quatrefoils.

There are buildings in which, though the upper roof is shown, there is a preparation for an inner roof; such is Chester cathedral, where only the lady chapel, and the aisles of the choir, are groined, and the whole of the rest of the church is open; but on the top of the shafts are the commencement springing of a stone groined roof. There is a chapel in a church in Cambridgeshire, Willingham, between Ely and Cambridge, which has a very singular roof; stone ribs rise like the timber ones, the intervals are pierced, and the slope of the roof is of stone; it is high pitched, and the whole appears of decorated character.

The second division, or inner roofs, are very various; from history it seems as if the most early inner roof was flat over the beams, and these were planked and painted, as at St. Alban's and Peterborough. The latter is, indeed, a singularly beautiful relic; it has lately been repainted, as it was originally, and now presents an appearance of rich mozaic, like a carpet full of stiff lines, and its general division is into lozenges, with flowers of Norman character, and the whole according in design with the ornaments of that style. This kind of roof most likely contributed much, especially when the exterior roof was covered with shingles, to spread those destructive fires which we so frequently read of in the history of the early churches. There are some roofs of this construction, in country churches, but generally of a very late date, and sometimes painted with wretched attempts at clouds.

There does not seem to be any wooden inner roofs, except plaster groining, now remaining, till we come to the perpendicular ordinary style of roofing, which was rich, though easily

constructed; a rib crossed above the pier, with a small flat arch, and this was crossed by another in the centre of the nave, and the spaces thus formed were again divided by cross ribs, till reduced to squares of two or three feet; and at each intersection, a flower, shield, or other ornament, was placed. This roof was sometimes in the aisles made sloping, and occasionally coved. In a few instances, the squares were filled with fans, &c. of small tracery.

The next and most important mode of interior roofing, is the regular groined roof; and of this description we have a regular and valuable series, from the plain Norman round arched roof, to the elaborate pendanted roof of Henry the VII.'s chapel.

The various Norman crypts, and some small churches, give very good specimens of the Norman roof, which has simply four cross springers, often without straight ribs from the opposite piers. The cross springers were ornamented in the usual manner with carvings of zigzag and other Norman ornaments. The first pointed roof added nothing to the Norman, in ribs, except the one from pier to pier. The ribs were often enriched by the toothed ornament, and generally a boss or knot at the centre intersections. Canterbury, some parts of Lincoln, but above all, Salisbury cathedral, are admirable specimens of these roofs, which were erected mostly in the time of the Early English style, or attached to buildings of that date.

The next advance appears in the roof of the nave at Wells cathedral; in this a plain rib runs longitudinally at the top, crossing the rib from the piers, and also the intersection of the cross springers, and another rib runs crossways at the top of the window arches, crossing the centre intersection. To this soon succeeded the multiplication of the ribs, which meet the longitudinal straight cross rib, and at their intersections have bosses. To this is added, in the richer roofs, short ribs running from one of these bosses to another, and these are increased in the later roofs, till the whole is one series of net work, of which the roof of the choir at Gloucester, is one of the most complicated specimens. The later monumental chapels and statuary niches, mostly present in their roofs very complicated tracery.

Of the ribbed roofs, which are rich without being gorgeous, perhaps York minster exhibits a specimen not inferior to any other.

We now come to a new and most delicate description of roof, that of *fan tracery*, of which probably the earliest, and certainly one of the most elegant, is that of the cloisters at

Gloucester. In these roofs, from the top of the shaft springs a small fan of ribs, which doubling out from the points of the pannels, ramify on the roof, and a quarter or half circular rib forms the fan, and the lozenge interval is formed by some of the ribs of the fan running through it, and dividing it into portions, which are filled with ornament. King's college chapel, Cambridge, Henry the VII.'s chapel, and the Abbey church at Bath, are the best specimens, after the Gloucester cloisters; and to these may be added the aisles of St. George's, Windsor, and that of the eastern addition to Peterborough. To some of these roofs are attached pendants, which, in Henry the VII.'s chapel, come down as low as the springing line of the fans.

The roof of the nave and choir of St. George's, Windsor, is very singular, and perhaps unique. The ordinary proportion of the arches and piers is half the breadth of the nave; this makes the roof compartments two squares, but at Windsor the breadth of the nave is nearly three times that of the aisles, and this makes a figure of about three squares. The two exterior parts are such as, if joined, would make a very rich ribbed roof; and the centre compartment, which runs as a flat arch, is filled with tracery pannels, of various shapes, ornamented with quatrefoils, and forming two halves of a star; in the choir the centre of the star is a pendant. This roof is certainly the most singular, and perhaps the richest in effect of any we have; it is profusely adorned with bosses, containing shields, &c.

There still remains one more description of roof, which is used in small chapels, but not common in large buildings; this is the arch roof; in a few instances it is found plain, with a simple ornament at the spring and the point, and this is generally a hollow moulding with flowers, &c. but it is mostly pannelled. Of this roof the nave of Bath is a most beautiful specimen. The arch is very flat, and is composed of a series of small rich pannels, with a few large ones at the centre of the compartments formed by the piers. Another beautiful roof of this kind is the porch to Henry the VII.'s chapel; but this is so hid, from the want of light, as to be seldom noticed.

The ribbed roofs are often formed of timber and plaster, but are generally coloured to represent stone work.

There may be some roofs of different arrangements from any of these; but in general they may be referred to one or other of the above heads.

Miscellaneous Remarks on Buildings of English Architecture.

Having now given an outline of the details of the different styles, it remains to speak of a few matters which could not so well be previously noticed. As one style passed gradually into another, there will be here and there buildings partaking of two, and there are many buildings of this description whose dates are not at all authenticated. Litchfield cathedral is a fine instance of the gradation from richer Early English into Decorated, as are some of those delicate monuments, the crosses of Edward the I. and many of the Lincolnshire spires. There are also many beautiful gradations from Decorated to Perpendicular. Of these, the choir of York, and the upper part of the two towers at the west end, and the remains of Melrose abbey, may be mentioned.

There is one building which deserves especial mention, from the singularity of its character, ornaments, and plan; this is Roslyn chapel. It is certainly unclassable as a whole, being unlike any other building in Great Britain of its age, (the latter part of the fifteenth century,) but if its details are minutely examined, they will be found to accord most completely in the ornamental work with the style then prevalent, though debased by the clumsiness of the parts, and their want of proportion. There seems little doubt that the designer was a foreigner, or at least took some foreign buildings for his model.

It will now be proper to add a few words on the alterations and additions which most ecclesiastical edifices have received; and some practical remarks as to judging of their age. The general alteration is that of windows, which is very frequent; very few churches are without some Perpendicular windows. We may therefore pretty safely conclude that a building is at least as old as its windows, or at least that part is so which contains the windows. But we can by no means say so with respect to doors, which are often left much older than the rest of the building.

A locality of style may be observed in almost every county, and in the districts where flint abounds, it is sometimes almost impossible to determine the date of the churches, from the absence of battlements, architraves, and buttresses; but wherever stone is used, there is generally enough of indication to assign each part to its proper style, and with due regard to do the same with plates of ordinary correctness, a little habitual attention would enable many persons to judge at once, at the sight of a plate or drawing, of its correctness, from its consistency, or the contrary, with the details of its apparent style.

In a sketch like the present, where the Author is confined to a certain space, it is impossible to notice every variety; but at least he now presents the world, for the first time, with a rational arrangement of the details of a mode of architecture on many accounts valuable, and certainly the most proper for ecclesiastical edifices. Still further to enable the reader to distinguish the principles of Grecian and English architecture, he adds a few striking contrasts, which are formed by those principles in buildings of real purity, and which will at once convince any unprejudiced mind of the impossibility of any thing like a good mixture.

Grecian.	*English.*
The general running lines are horizontal.	The general running lines are perpendicular.
Arches not necessary.	Arches a really fundamental principle, and no pure English building or ornament can be composed without them.
An entablature absolutely necessary, consisting always of two, and mostly of three distinct parts, having a close relation to, and its character and ornaments determined by the columns.	No such thing as an entablature composed of parts, and what is called a cornice, bears no real relation to the shafts which may be in the same building.
The columns can support nothing but an entablature, and no arch can spring directly from a column.	The shafts can only support an arched moulding, and in no case a horizontal line.
A flat column may be called a pilaster, which can be used as a column.	Nothing analogous to a pilaster; every flat ornamented projecting surface, is either a series of pannels, or a buttress.
The arch must spring from a horizontal line.	No horizontal line necessary, and never any but the small cap of a shaft.
Columns the supporters of the entablature.	Shaft bears nothing, and is only ornamental, and the round pier still a pier.

Grecian and English architecture contrasted.

Grecian.	*English.*
No projections like buttresses, and all projections stopped by horizontal lines.	Buttresses essential parts, and stop all horizontal lines.
Arrangement of pediment fixed.	Pediment only an ornamented end wall, and may be of almost any pitch.
Openings limited by the proportions of the column.	Openings almost unlimited.
Regularity of composition on each side of a centre necessary.	Regularity of composition seldom found, and variety of ornament universal.
Cannot form good steeples, because they must resemble unconnected buildings piled on each other.	From its perpendicular lines, may be carried to any practicable height, with almost increasing beauty.

In the foregoing details we have said nothing of castellated or domestic architecture; because there does not appear to be any remains of domestic buildings, so old as the latest period of the English style, which are unaltered; and because the castellated remains are so uncertain in their dates, and so much dilapidated or altered, to adapt them to modern modes of life or defence, that little clear arrangement could be made, and a careful study of ecclesiastical architecture will lead any one, desirous to form some judgment of the character of these buildings, to the most accurate conclusions on the subject which can well be obtained in their present state.

Description of Plate I.

In order that the plate may be kept free from figures, which would have taken off greatly from its good effect, a description of what it contains is annexed without letters of reference. And it may be necessary to state, that in order to comprise as much as possible of the different styles in a small space, there has been an unavoidable departure from the relative proportion of parts in several instances, but not to any very great extent.

Description of Plate first.

The upper part of the plate contains sixteen detached specimens, which, beginning at the left hand at the top, are as follow:

1st, The plain semi-circular arch.

2nd, The segmental arch.

3rd, The equilateral arch.

4th, The drop arch.

5th, The lancet arch.

6th, The horse-shoe arch.

7th, The ogee or contrasted arch.

8th, The four-centred or Tudor arch.

9th, A plain circular trefoil window, with ornamented points.

10th, A plain trefoil window head.

11th, A triangular pannel feathered in three divisions, each of which is again feathered.

12th, The straight-headed cinquefoil, so much used in small tracery of windows, in the eastern part of the kingdom.

13th, A plain circular quatrefoil window.

14th, The usual mode of cinquefoiling an ogee head, and its insertion in a transom.

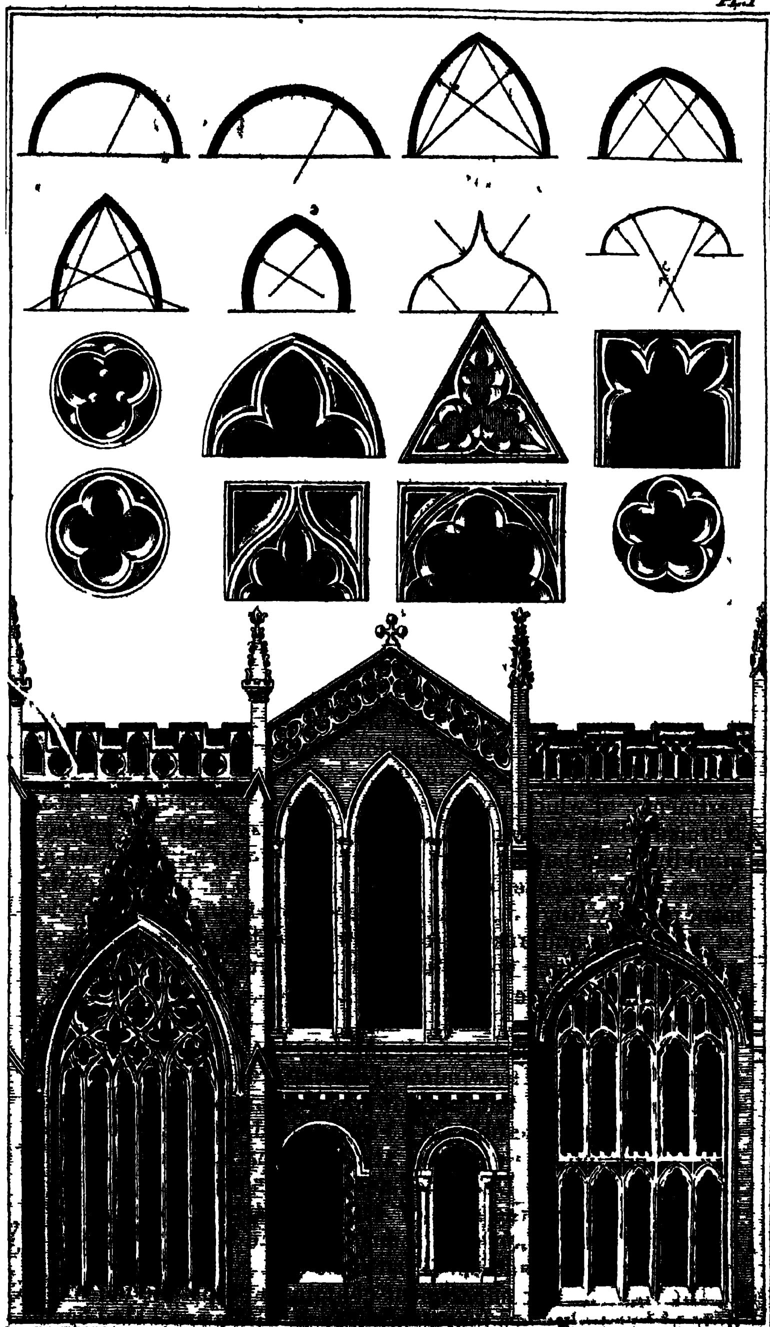
15th, A very beautiful mode of double feathering a cinquefoil, from the east window at York.

16th, A plain circular cinquefoil window.

The lower design is divided by buttresses into three compartments, of which the lower part of the centre contains two Norman windows, one with shafts, the other with the zigzag moulding, and having between them a Norman buttress, and a Norman cornice over them. The upper part of this compartment is Early English, having three windows with shafts divided by bands, and resting on a tablet. The pediment has a projecting parapet with a cornice moulding under it, and a cap moulding above. This parapet is ornamented with sunk quatrefoils.

The left hand compartment, and its two buttresses, are Decorated English. The window of flowing tracery is of the style of that in the west end of Newark, but much of its delicate small ornaments are obliged to be omitted, on account of its size. The canopy is executed at Chester cathedral. The cornice is the ordinary Decorated cornice with flowers. The battlement is that of the nave of York minster. The pinnacles are of the description very common in the west of England, with square bases and small battlements.

The right-hand compartment contains a perpendicular window of five lights in a four-centred arch, with a crocketed ogee



Barlow sculp



J. Rickman Del.

Le Keux Sculp.

canopy. It is divided by a transom, and has the transom moulding battlemented. This window is of simple construction, and is executed with slight variations in various parts.

The cornice is that of the upper roof of the Abbey-church at Bath, and the battlements are also taken from thence; but from the small size of the plate, both are obliged to be much simplified as to their mouldings. The pinnacles are the ordinary pinnacles of this style.

Plate II. affords an example of the square-headed door of the Perpendicular style; it has a shaft supporting the inner moulding of the arch, and another supporting the exterior mouldings, which forms also the square, and both are included in a hollow moulding. The dripstone is nearly the most frequent plain dripstone, and the cornice shews the effect of the introduction of flowers.

Plates of almost all the buildings mentioned in this sketch, may be found in one or other of the following works, which all contain plates of good character, though of course perhaps not all of equal correctness in drawing the detail

The Cathedrals, &c. published by the Society of Antiquaries,
Carter's Ancient Architecture,
King's Munimenta Antiqua,
Halfpenny's Engravings of York Minster,
Buckler's Views of the Cathedrals,
Britton's Architectural Antiquities,
Storer and Greig's Illustrations of Pennant's London,
——————— Antiquarian and Topographical Cabinet,
——————— Ancient Relics,
Lyson's Magna Brittanica,
Britton and Brayley's Beauties of England,
Archæologia,
Chalmer's History of Oxford.

GRECIAN ARCHITECTURE.

The many valuable treatises and excellent delineations of the Grecian and Roman buildings, and the details of their parts, will render unnecessary that minuteness in this dissertation, which, from the total absence of a previous system, it became necessary to adopt in the description of the English styles. But in this sketch something of a similar plan will be followed, first giving the name and grand distinctions of the orders, then describing the terms and names of parts necessary for those who have not paid attention to the subject to understand, and a concise description of each order will follow; but from the diversity of judgment prevailing, it will be most proper to leave the reader to select his own examples, as in this country we have not, as in the English architecture, the originals to study, but a variety of copies, adapted to the climate and the convenience of modern times.

In dividing the Grecian and Roman architecture, the word order is used, and much more properly than style; the English styles regarded not a few parts, but the composition of the whole building; but a Grecian building is denominated Doric or Ionic, merely from its ornaments; and the number of columns, windows, &c. may be the same in either order, only varied in proportion.

The orders are generally considered to be five, and are usually enumerated as follows:

Tuscan, of which the usual height of the col. is	7 diameters.
Doric, - - -	8
Ionic, - - -	9
Corinthian, - - -	10
Composite, - - -	10

Their origin will be treated of hereafter. Their prominent distinctions are as follow:

The *Tuscan* is quite plain, without any ornament whatever.

The *Doric* is distinguished by the channels and projecting intervals in the frieze, called *triglyphs*.

The *Ionic* by the ornaments of its capital, which are spiral, and are called *volutes*.

The *Corinthian* by the superior height of its capital, and its being ornamented with leaves, which support very small volutes.

The *Composite* has also a tall capital with leaves, but is distinguished from the Corinthian by having the large volutes of the Ionic capital.

Division of a complete order.

A complete order is divisible into three grand divisions, which are occasionally executed separately, viz.

The *column*, including its base and capital,

The *pedestal*, which supports the column,

The *entablature*, or part above and supported by the column.

These are again each subdivided into three parts.

The *pedestal* into base or lower mouldings; *diado* or *die*, the plain central space; and *surbase* or upper mouldings.

The *column* into base or lower mouldings, *shaft* or central plain space, and *capital* or upper mouldings.

The *entablature* into *architrave*, or part immediately above the column; *frieze* or central flat space; and *cornice* or upper projecting mouldings.

These parts may be again divided thus: the lower portions, viz. the base of pedestal, base of column, and architrave, divide each into two parts; the first and second into plinth and mouldings, the third into face or faces, and upper moulding or tenia.

Each *central* portion, as dado of pedestal, shaft of column, and frieze, is undivided.

Each *upper* portion, as surbase of pedestal, capital of column, cornice of entablature, divides into three parts: the first into *bedmould*, or the part under the corona; corona, or plain face; and *cymatium*, or upper moulding.

The *capital*, into *neck*, or part below the ovolo; *ovolo* or projecting round moulding; and *abacus* or *tile*, the flat upper moulding mostly nearly square. These divisions of the capital, however, are less distinct than those of the other parts.

The *cornice* into *bedmould*, or part below the corona; *corona*, or flat projecting face; *cymatium*, or moulding above the corona.

Besides these general divisions, it will be proper to notice a few terms often made use of. The ornamental moulding running round an arch, or round doors and windows, is called an *architrave*.

An ornamental moulding for an arch to spring from, is called an *impost*.

The stone at the top of an arch, which often projects, is called a *key-stone*.

The small brackets under the corona in the cornices, are called *mutules* or *modillions;* if they are square, or longer in front than in depth, they are called *mutules*, and are used in the Doric order. If they are less in front than their depth, they are called *modillions*, and in the Corinthian order have carved leaves spread under them.

A *truss* is a modillion enlarged, and placed flat against a wall, often used to support the cornice of doors and windows.

A *console* is an ornament like a truss carved on a key-stone.

Trusses, when used under modillions in the frieze, are called *cantalivers*.

The space under the corona of the cornice, is called a *soffit*, as is also the under side of an arch.

Dentils are ornaments used in the bedmould of cornices; they are parts of a small flat face, which is cut perpendicularly, and small intervals left between each.

A flat column is called a *pilaster;* and those which are used with columns, and have a different capital, are called *antæ*.

A small height of pannelling above the cornice, is called an *attic*, and in these pannels, and sometimes in other parts, are introduced small pillars, swelling towards the bottom, called *balustres*, and a series of them a *balustrade*.

If the joints of the masonry are channelled, the work is called *rustic*, which is often used as a basement for an order.

Columns are sometimes ornamented by channels, which are called *flutes*. These channels are sometimes partly filled by a lesser round moulding; this is called *cabling* the flutes.

For the better understanding the description to be given of the orders, it will be proper first to notice the different mouldings, which by different combinations form their parts.

The most simple mouldings are, 1st, the *Ovolo*, or quarter round, see pl. III. fig. 1.

2nd, The *cavetto*, or hollow, fig. 2.

3rd, The *torus*, or round, fig. 3.

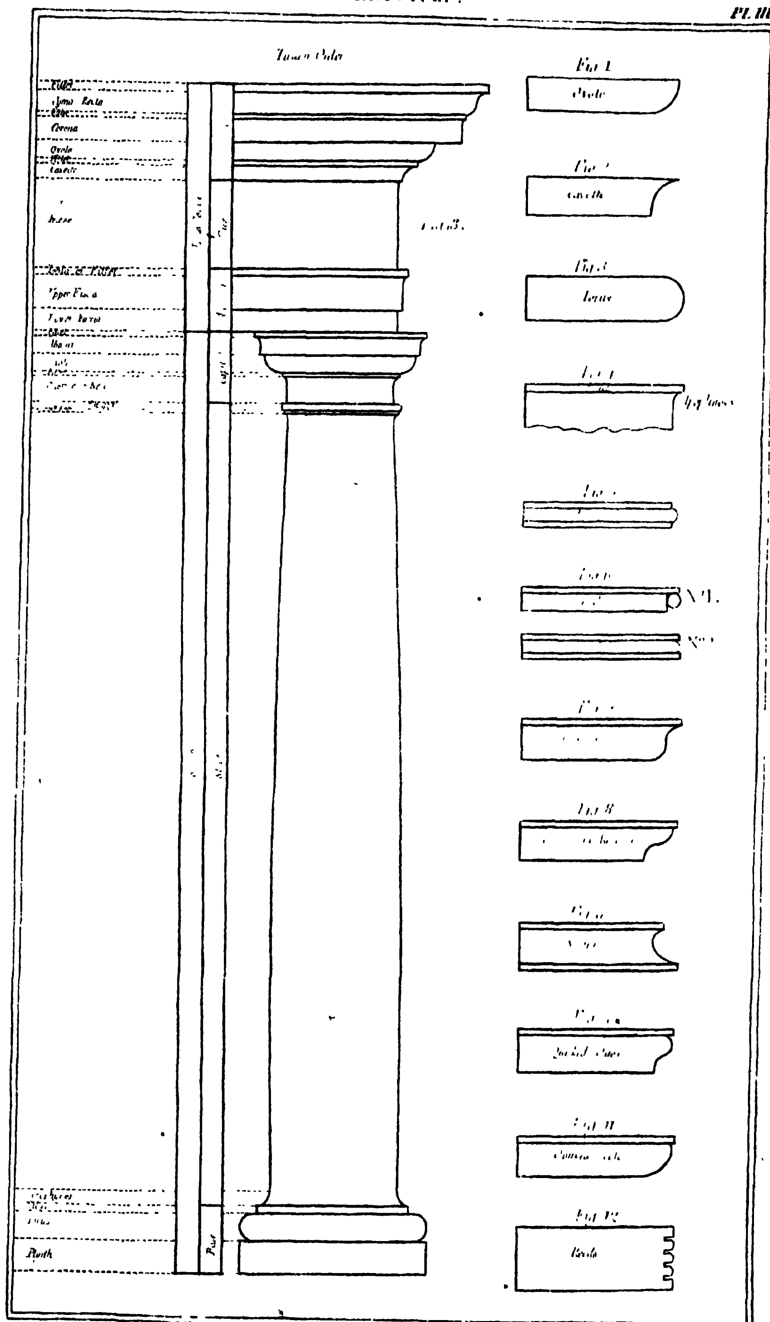
From the composition of these are formed divers others, and from the arrangement of them, with plain flat spaces between, are formed cornices and other ornaments. A large flat space is called a *corona* if in the cornice; a *fascia* in the architrave; and the frieze itself is only a flat space. A small flat face is called a *fillet*, or listel, and is interposed between mouldings to divide them.

A fillet is, in the bases of columns and some other parts, joined to a face, or to the column itself by a small hollow, then called *apophyges*, fig. 4.

The torus, when very small, becomes an *astragal*, which projects, fig. 5; or a *bead*, which does not project, fig. 6, No. 1, 2.

Compound mouldings are, the *cyma recta*, which has the hollow uppermost and projecting, fig. 7.

The *cyma reversa*, or *ogee*, which has the round uppermost and projecting, fig. 8.


Tuscan Order
Cyma Recta
Corona
Ovolo
Cavetto
Frieze
Upper Fascia
Plinth
Fig. 1
Ovolo
Cavetto
Fig. 3
Fig. 8
Fig. 11
Fig. 12
Quirked Ovolo
Beads

The *scotia;* which is formed of two hollows, one over the other, and of different centres, fig. 9.

In the Roman works, the mouldings are generally worked of equal projection to the height, and not bolder than the above regular forms; but the Grecian mouldings are often bolder, and worked with a small return, technically called a *quirk,* and these are of various proportions.

The ogee and ovolo are most generally used as represented by fig. 10 and 11.

Several beads placed together, or sunk in a flat face, are called reedings, see fig. 12.

All these mouldings, except the fillet, may be occasionally carved, and they are then called *enriched mouldings.*

From these few simple forms, by adding astragals and fillets, and combining differently ornamented mouldings, faces, and soffits, are all the cornices, pannels, &c. formed, and the modern compositions in joiners' work, &c. are very numerous, and too well known to need describing.

Tuscan Order.

Though this is not, perhaps, the most ancient of the orders, yet, from its plainness and simplicity, it is usually first noticed. Its origin is evidently Italian; for the Grecian work, however plain, has still some of the distinctive marks of massive Doric, whilst the Tuscan always bears clear marks of its analogy to the Roman Doric.

The pedestal, when used, is very plain, but it is more often set on a plain square block plinth, which suits the character of the order better than the higher pedestal. This block projects about half the height of the plinth of the base beyond its face.

The column, including the base and capital, is about seven diameters high. The column, in this, and indeed in all the orders, is diminished the upper two-thirds of its height, so that the diameter under the neck of the capital is from one-sixth to one-fourth less than that just above the base. This diminution is not conical, but bounded by a curved line, which is variously determined, but does not differ much from what an even spring would assume, if one part of it were bound, in the direction of the axis of the shaft, to the cylindrical third, and then, by pressure at the top only, brought to the diminishing point.

The Tuscan base is half a diameter in height, and consists of a plain torus with a fillet and apophyges, which last is part

of the shaft, and not of the base, as indeed all apophygæ are considered to be; and also all the astragals underneath the capitals, as well as the upper fillet of the base in all the richer orders, and in masonry should be executed on the shaft stones.

The capital of the Tuscan order is (exclusive of the astragal) half a diameter in height, and consists of a neck on which is an ovolo and fillet, joined to the neck by an apophyges, and over the ovolo a square tile, which is ornamented by a projecting fillet.

The shaft of this order is never fluted, but some architects have given to this order, and some have even added to the richer orders, an ornament (if so it may be called) of large square blocks as parts of the shaft, which are called rustications, and are sometimes roughened.

The Tuscan entablature should be quite plain, having neither mutules nor modillions. The architrave has one or sometimes two faces, and a fillet; the frieze quite plain, and the cornice consisting of a plain cyma recta for cymatium, and the corona with a plain fillet, and small channel for drip in the soffit. The bedmould should consist of an ovolo fillet and cavetto.

This Tuscan is that of Palladio; some other Italian architects have varied in parts, and some have given a sort of block modillions like those used in Covent-Garden church; but these are of wood, and ought not to be imitated in stone.

This order is little used, and will most likely, in future, be still less so, as the massive Grecian Doric is an order equally manageable, and far more elegant.

Having explained the parts of one order, it will be necessary to make a few remarks, which could not so well be previously introduced.—If pilasters and columns are used together, and they are of the same character, and not antæ, the pilasters should be diminished like the columns; but where pilasters are used alone, they may be undiminished

The moulding under the cymatium, which, in rich orders, is often an ogee, is part of the corona, and as such is continued over the corona in the horizontal line of pediments, where the cymatium is omitted; and is also continued with the corona in interior work, where the cymatium is often with propriety omitted.

In pediments, whose cornices contain mutules, modillions, or dentils, those in the raking cornice must be placed perpendicularly over those in the horizontal cornice, and their sides must be perpendicular, though their under parts have the rake of the cornice.

Doric Order.

The ancient Grecian Doric appears to have been an order of peculiar nobility, simple and bold, its ornaments were the remains of real utility, and perhaps originally it was worked with no moulding but the cymatium, to cover the ends of the tiles, its triglyphs being the ends of the beams, and its mutules those of the rafters. In after times its proportions were made rather less massive, and its mouldings and ornaments, though not numerous, were very beautiful. The Romans considerably altered this order, and by the regulations they introduced, rendered it peculiarly difficult to execute on large buildings. As the examples of the two countries are very different, we shall treat of them separately, and first therefore of the

Grecian Doric.

The columns of this order were, in Greece, generally placed on the floor, without pedestal and without base; the capital, which occupied a height of about half a diameter, had no astragal, but a few plain fillets, with channels between them, under the ovolo, and sometimes a small channel under the fillets. The ovolo is generally flat, and of great projection, with a quirk or return. On this was laid the abacus, which was only a plain tile, without fillet or ornament.

In the division of the entablature, the architrave and frieze have each more than a third in height, and the cornice less. The architrave has only a plain broad fillet, under which are placed the drops or guttæ, which appear to hang from the triglyphs.

The triglyph, in Greece, appears to have been generally placed at the angle, thus bringing the interior edge of the triglyph over the centre of the angular column. The metope, or space between the triglyphs, being the square of the height of the frieze, and a mutule was placed not only over each triglyph, but also over each metope, and it appears probable that the triglyphs were often omitted, except over the centre of each column, and at the angle, and hence the order would be easily worked at any desirable intercolumniation. The cornice of this order, in Greece, consisted of a plain face, under the mutule, which was measured as part of the frieze, and then the mutule, which projected sloping forward under the corona; so that the bottom of the mutule in front was considerably lower than at the back, where, in some examples, an ogee is placed under the mutule. Over the corona was commonly a small ovolo and fillet, and then a larger ovolo and fillet for the cymatium.

The ornaments of this order, in Greece, were, 1st, the flutings of the column, which are peculiar to the order, and are twenty in number, shallow, and not with fillets between them, but sharp edges. These flutes are much less than a semicircle, and should be elliptic.

2d, At the corner, in the space formed in the soffit of the corona, by the interval between the two angular mutules, was sometimes placed a flower, and the cymatium of the cornice had lions' heads, which appear to have been real spouts.

3d, In addition to the drops under the triglyph, the mutules also have several rows of drops of the same shape and size.

This order appears in general to have been worked very massive, the best examples are about six diameters high, which is lower than the Italians usually worked the Tuscan; but this gave peculiar nobility to the temples in which it is thus employed. It does not appear that a pedestal was used in Greece with this order.

Roman Doric.

This differs from the Grecian in several important particulars, which will appear from the following rules, from the strictness of which follows that extreme difficulty of execution which has been so often complained of in this order: 1st, The triglyphs must be precisely over the centre of the columns. 2d, the metopes must be exact squares; 3d, the mutules also must be exact squares.

As, therefore, the intercolumniation must be of a certain number of triglyphs, it will be easily conceived how difficult it will be, in large buildings, where a triglyph is several feet, to accommodate this order to the internal arrangements.

The Roman Doric is sometimes set on a plinth, and sometimes on a pedestal, which should be of few and plain mouldings. The bases usually employed, are either the attic base of a plinth, lower torus, scotia, and upper torus, with fillets between them, or the proper base of one torus and an astragal; or, in some instances, of a plinth and simple fillet. The shaft, including the base and capital, each of which is half a diameter, is generally eight diameters high, and is fluted like the Grecian. The capital has an astragal and neck under the ovolo, which has sometimes three small fillets, projecting over each other, and sometimes another astragal and fillet. The ovolo should be a true quarter round. The abacus has a small ogee and fillet on its upper edge.

The architrave has less height than the Grecian, being only two-thirds of the frieze, which is equal in height to the cornice.

In a few instances the architrave has two faces, but mostly only one.

The frieze has nothing peculiar to this mode; if plain, its metopes being, as before observed, square.

The cornice differs much from the Grecian, having its soffit flat, and the mutules square, with a square interval between them. The Grecian drops in the mutules generally appear in front, below the mutules; but the Roman do not, and are sometimes omitted.

The cymatium is often a cavetto, with an ogee under it, and sometimes a cyma recta. The mutules have a small ogee, which runs round them, and also round the face they are formed of; and under the mutules are an ovolo and small fillet, and the flat fillet which runs round the top of the triglyphs here belongs to the cornice, and not, as in the Grecian, to the frieze.

In some instances, dentils appear to have been used in the Doric cornice at Rome, but there are not many examples of this practice.

The Roman Doric is susceptible of much ornament, for in addition to the flutes, the guttæ of the triglyphs, and the roses in the soffit of the corona, the neck of the capital has sometimes eight flowers or husks placed round it, the ovolo carved, and the metopes in the frieze filled with alternate ox skulls and pateræ, or other ornaments. In interior decorations sometimes one or two of the mouldings of the cornice are enriched; but with all this ornament, the Roman Doric is far inferior, in real beauty, to the Grecian.

Ionic Order.

As the Greeks and Romans differed much in their modes of working the Doric order, so there was considerable difference in their execution of the Ionic, though by no means so great as in the former.

The distinguishing feature of this order is the capital, which has four spiral projections called volutes. These in Greece were placed flat on the front and back of the column, leaving the two sides of a different character, and forming a balustre; but this at the external angle producing a disagreeable effect, an angular volute was sometimes placed there, shewing two volutes to each exterior face, and a balustre to each interior; but this not forming a good combination, a capital was invented with four angular volutes, and the abacus with its sides hollowed out. This is called the *modern* Ionic capital. In the *ancient*, the list or spiral line of the volute runs along the face of the abacus, straight under the ogee; but in the

modern, this list springs from behind the ovolo, and in the hollow of the abacus, which is an ovolo, fillet, and cavetto, is generally placed a flower.

The Ionic shaft, including the base, which is half a diameter, and the capital to the bottom of the volute generally a little more, is nine diameters high.

The pedestal is a little taller and more ornamented than the Doric.

The bases used to this order are very various; some of the Grecian examples are of one torus and two scotia, with astragals and fillets; others of two large tori and a scotia of small projection; but the attic base is very often used, and with an astragal added above the upper torus, makes a beautiful and appropriate base for the Ionic.

The cornices of this order may be divided into three divisions; 1st, the plain Grecian cornice; 2nd, the dentil cornice; 3d, the modillion cornice.

In the first, the architrave is often of one face, the frieze plain, and the cornice composed of a corona with a deep soffit, and the bedmould moulding hidden by the drip of the soffit, or coming very little below it, and sometimes with a plain dentil set close under the corona. The cymatium generally a cyma recta, and ogee under it.

The second, which was mostly used with the ancient capital at Rome, has generally two faces in the architrave, and the cornice, which is rather more than one-third of the height of the entablature, has a corona with a cyma recta and ogee for cymatium, and for bedmould a dentil face between an ovolo and ogee. The soffit of the corona sometimes ornamented.

The third, or modillion entablature, has the same architrave, frieze, and cymatium of its cornice, as the last, but under the soffit of the corona are placed modillions, which are plain and surrounded by a small ogee; one must be placed over the centre of each column, and one being close to the return makes a square pannel in the soffit at the corner, and between each modillion, which is often filled with a flower. The bedmould below is generally an ovolo, fillet, and cavetto.

It was once the custom to work the Ionic frieze projecting like a torus, thus giving an awkward weight to an order which ought to be light. The introduction of good Grecian models has driven out this impropriety, and much improved the present execution of the order, which is very beautiful, if well executed.

The Ionic shaft may be fluted in twenty-four flutes, with fillets between them; these flutes are semi-circular. This order may be much ornamented if necessary, by carving the

ovolo of the capital, the ogee of the abacus, and one or two mouldings of both architrave and cornice; but the ancient Ionic will look extremely well without any ornament whatever.

Corinthian Order.

This order originated in Greece, and the capital is said to have been suggested by observing a tile placed on a basket left in a garden, and round which sprung up an acanthus. All the other orders have, in various countries and situations, much variety; but the Corinthian, though not without slight variations even in the antique, is much more settled in its proportions, and its greater or less enrichment is the principal source of variety.

The capital is the great distinction of this order, its height is more than a diameter, and consists of an astragal, fillet, and apophyges, all which are measured with the shaft, then a bell and horned abacus. The bell is set round with two rows of leaves, eight in each row, and a third row of leaves support eight small open volutes, four of which are under the four horns of the abacus, and the other four, which are often interwoven, are under the central recessed part of the abacus, and have over them a flower or other ornament. These volutes spring out of small twisted husks placed between the leaves of the second row, and which are called *caulicoles.* The abacus consists of an ovolo, fillet, and cavetto, like the modern Ionic. There are various modes of indenting the leaves, which are called, from these variations, *acanthus, olive,* &c. The column, including the base of half a diameter, and the capital, is ten diameters high.

If a pedestal is used, it should have several mouldings, some of which may, if necessary, be enriched. The base may be either an attic base, or with the addition of three astragals, one over each torus, and one between the scotia and upper torus; or a base of two tori and two scotiæ, which are divided by two astragals: one or two other varieties are sometimes, but not often, used.

The entablature of this order is very fine. The architrave has mostly two or there faces, which have generally small ogees or beads between them.

The frieze is flat, but is often joined to the upper fillet of the architrave by an apophyges.

The cornice has both modillions and dentils, and is usually thus composed: above the corona is a cymatium, and small ogee; under it the modillions, whose disposition, like the Ionic, must be one over the centre of the column, and one close to the return of the cornice.

These modillions are carved with a small balustre front, and a leaf under them; they are surrounded at the upper part by a small ogee and fillet, which also runs round the face they spring from. Under the modillions is placed an ovolo, and then a fillet and the dentil face, which is often left uncut in exterior work. Under the dentils are a fillet and ogee. In some cases this order is properly worked with a plain cornice, omitting the modillions, and leaving the dentil face uncut.

The enrichments of this order may be very considerable; some of the mouldings of the pedestal and base may be enriched. The shaft may be fluted as the Ionic, in twenty-four flutes, which may be filled one-third high by staves, which is called *cabling* the flutes. The small mouldings of the architrave, and even some of its faces, and several mouldings of the cornice, may be enriched; the squares in the soffit of the corona pannelled and flowered, and the frieze may be adorned with carvings. But though the order will bear all this ornament without overloading it, yet, for exteriors, it seldom looks better than when the capitals and the modillions are the only carvings.

The Composite Order.

The Romans formed this order by mixing the Corinthian and Ionic capitals; like the Corinthian, the capital is its principal distinction. This is of the same height as the Corinthian, and it is formed by setting, on the two lower rows of leaves of the Corinthian capital, the modern Ionic volutes, ovolo, and abacus. The small space left of the bell is filled by caulicoles, with flowers, and the upper list of the volute is often flowered.

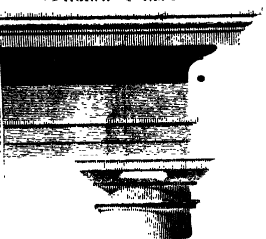
The column is of the same height as the Corinthian, and the pedestal and base differ very little from those of that order, the pedestal being sometimes a little plainer, and the base having an astragal or two less.

The entablature mostly used with this order is plainer than the Corinthian, having commonly only two faces to the architrave, the upper mouldings being rather bolder; and the cornice is different, in having, instead of the modillion and dentil, a sort of plain double modillion, consisting of two faces, the upper projecting farthest, and separated from the lower by a small ogee. Under this modillion is commonly a large ogee astragal and fillet.

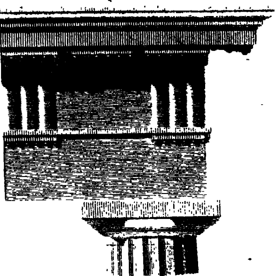
A plain cornice, nearly like that used to the Corinthian order, is sometimes used to this order, and also a cornice with the modillions bolder, and cantalivers under them in the frieze.

This order may be enriched in the same manner as the Corinthian.

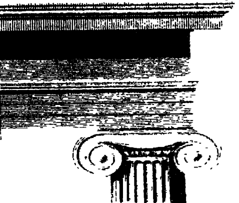
Tuscan Order



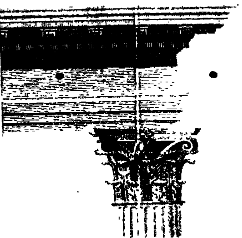
Grecian Doric



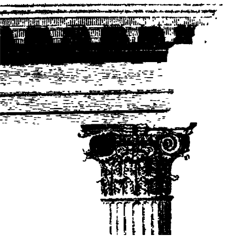
Grecian Ionic

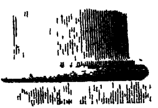


Corinthian Order



Composite Order

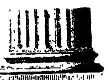




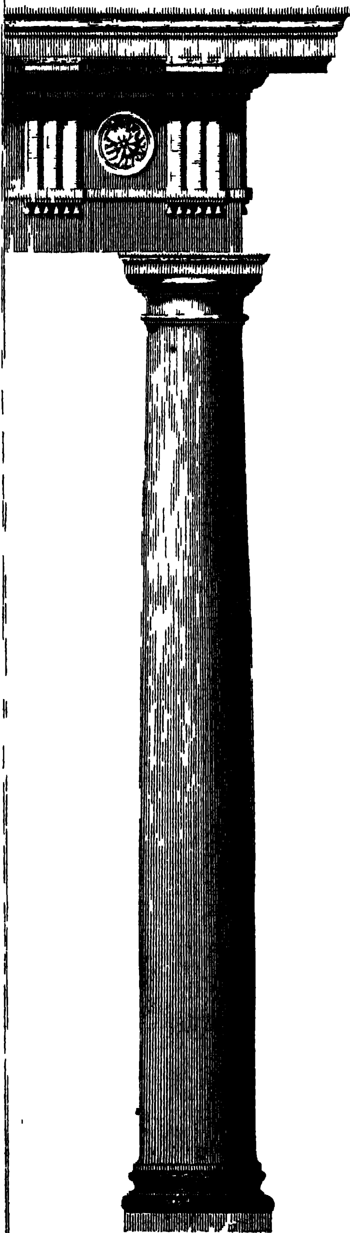




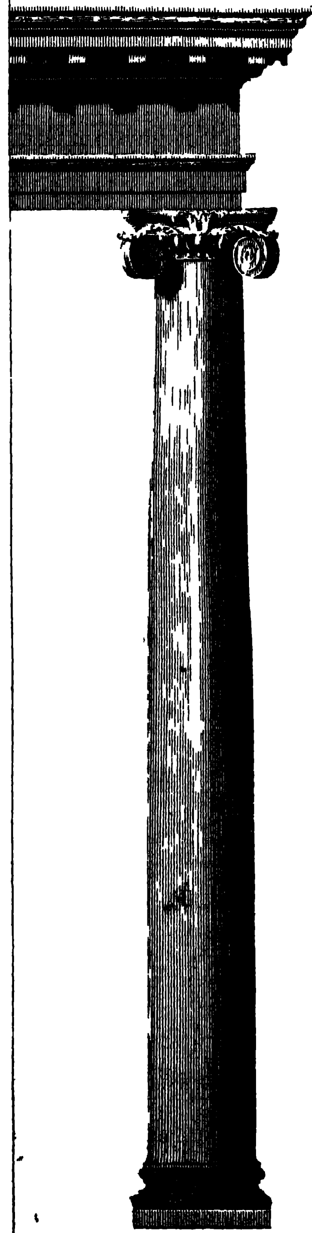




Roman Doric



Roman Ionic



Having gone through the most usual forms and distinctions of the orders, it is proper to say, that, even in Greece and Rome, we meet with specimens whose proportions and composition do not agree with either of them. These are comprised under the general name of composed orders, and though some are beautiful as small works, scarcely any of the ancient ones, are worthy of imitation in large buildings, and modern composition has run very wild, and produced scarcely any thing worth prolonging by description. There was, however, one attempt of a singular kind, made some years since by an architect at Windsor, who published a magnificent treatise, and executed one portico and a few door-cases in and near Windsor. This was H. Emlyn, who conducted the restoration of St. George's chapel. His order, he says, was first brought into his mind by the twin trees in Windsor forest. He makes an oval shaft rise about one-fourth of its height, and then two round shafts spring from it close to each other, and the diminution affords space for two capitals, which have volutes, and, instead of leaves, feathers like the caps of the knights of the garter. His entablature has triglyphs, and his cornice mutules. The triglyphs are ostrich feathers, the guttæ acorns, and the metopes are filled with the star of the garter.

To conceal the awkward junction of the two columns to the lower part, an ornament is placed there, which is a trophy with the star of the garter in the centre.

It is obvious that this order must be extremely unmanageable, as it is difficult, and indeed almost impossible, to make a good angle column, and if its entablature is proportioned tc the diameter of one column, it will be too small; if to the whole diameter, it will be too heavy, and a mean will give the capitals wrong; so that in any shape some error arises. In the portico above mentioned, the entablature is so light as to appear preposterous. This attempt is not generally known, as the book was very expensive, and the portico at a distance from a public road; but it deserves consideration, because, though the idea was new, its execution seems completely to have failed; and, indeed, in large designs, no composed order has ever yet appeared that can come into competition with a scrupulous attention to those excellent models of Greece and Rome, now, through the effects of graphic art, happily so familiar to almost every English architect.

BUILDING.

Bricklaying is the art of building with bricks.

Of Bricks.

Previous to entering upon details belonging exclusively to the art of bricklaying, we shall introduce an account of the manufacture and different sorts of bricks.

On comparing the strength and durability of modern bricks with those of the ancients, it is evident that the former are in every respect inferior. The ancients appear not only to have selected the best sort of clay, but to have combined it with other ingredients well adapted to improve its properties. Professor Pallas, on his last journey through the southern provinces of Russia, discovered, in the stupendous Tartar monuments, bricks which would scarcely yield to the hammer. Another circumstance contributing materially to the excellence of the bricks and tiles manufactured by the ancients, arose from their burning them uniformly, after they had been thoroughly dried. No doubt can be entertained, that if modern brickmakers were to pay more attention to their art, by digging the clay at proper seasons, exposing it much longer to the air than is done at present, working it sufficiently, bestowing more care upon the burning of the bricks, and that the latter operation may be done uniformly, making them much thinner than is prescribed by the standard form, we should be provided with bricks equal in point of strength and durability to the best of former times. In a variety of instances, persons may have it in their power to obviate some of these causes of defect, and it is therefore proper to mention them; but the state of society is not favourable to any general change in the system which brickmakers pursue; the expedition with which a given number of bricks can be furnished, and the cheapness of the rate at which they can be manufactured, are to them the primary objects of consideration; and the speculative builder cares little about the real value and durability of his edifice, provided the difference between the cost and sale price is sufficiently ample to recompense him to his satisfaction.

It is an erroneous notion that bricks may be made of any earth that is not stony, or even of sea ouse; too much sand

entering into their composition, renders them heavy and brittle, and too much fat argillaceous matter causes them to crack in drying: those only will burn red which contain iron particles. In England they are chiefly made of a motley, yellowish, or somewhat reddish fat clayey earth, commonly called *loam*. Those of Stourbridge clay, and Windsor loam, are esteemed the most proper and durable bricks, and they will stand very high degrees of heat without melting. The earth for this manufacture should not contain too many calcareous and ferruginous ingredients; as the former prevent the mass from becoming firm in burning, and occasion the bricks to crumble when exposed to the air; while a superabundance of iron particles retards the preparation of bricks so much as often to occasion considerable difficulty in giving them due consistence. This inconvenience may, however, be remedied, by allowing the clay to lie a considerable time under the influence of the atmosphere, then soaking it in pits, and afterwards working it well in the usual manner. The common potter's clay, which is also employed in the manufacture of bricks, is opaque, imparts a slight colour, sometimes yellowish, bluish, greenish, but more frequently of different shades of light grey; when kneaded and spread, it becomes smooth and glossy; it is soft, fat, and cold, somewhat agreeable to the touch, slightly adheres to the tongue, has a fine earthy fracture, and is very plastic. When of the best quality, it is not remarkable either for its lightness, or weight. By chemical examination it is found to consist of thirty-seven parts of pure argillaceous or clayey earth, and sixty-three parts of siliceous or flinty earth.

Of whatever description the earth intended for bricks may be, it ought to be dug after midsummer, that is, between the beginning of July and the latter end of October, before the first frost appears; it should be repeatedly worked with the spade during the winter, and not formed into bricks till the following spring. If the earth were not used till two or three years after it had been dug, the quality of the bricks produced would be very materially improved; and in all cases, the oftener it is turned and the more completely it is incorporated, the better will be the bricks.

The clay, before it is put into pits for soaking, must be broken as small as possible, and allowed to lie at least ten days; every stratum of twelve inches should be covered with water, in order that it may be uniformly softened. Two pits, at least, will be necessary for every brick manufactory, so that, after having been suffered to remain for five days, the second may be prepared, and thus the manufacture carried on without interruption. The earth should as much as possible be divested

of stony particles, and other extraneous matter, and should have sufficient time to mellow and ferment, otherwise it will be difficult to temper. On the treading and tempering, twice the customary quantity of labour ought to be bestowed. Much of the goodness of bricks depends upon the proper management of its first preparation, for the earth itself, previous to its being wrought, possesses very little tenacity; but by long exposure to the air and frost, and thoroughly working and incorporating it together, it is converted into a tough, gluey substance, in which state alone it is fit for moulding.

In the vicinity of London, coal ashes, and in other parts of the country, light sandy earth, is usually mixed with the clay, which, by such addition, is more easily and expeditiously wrought, and requiring rather less fuel, occasions some saving in the expense of burning the bricks; but here the advantages of it terminate; in other respects it is injurious rather than otherwise. If in tempering the earth, too much water be used, the bricks become dry and brittle; but if duly tempered, they will be smooth, solid, hard, and durable. A brick properly made, requires nearly as much earth as a brick and a half made in the common way, when too great a proportion of water has been added, which tends to render the bricks spongy, light, and full of flaws. As bricks made in the best manner are more solid and ponderous than the common ones, they require a much longer time to dry; they ought not to be burnt till they will give a hollow sound on collision. Proper attention to the drying of bricks is necessary to prevent their cracking and crumbling in the kiln.

Of whatever materials the kiln be constructed, each burning of from six to ten thousand bricks requires the fire to be kept up at least for twenty-four hours, and double that time for a number of from twelve to fifty thousand. The uniform increase of heat deserves particular attention; its duration should be regulated according to the season: in cold weather fire burns most fiercely. During the last twenty-four hours, the fire should be uninterruptedly supported by means of flues; but afterwards the fire should not be suddenly closed, as there is always some danger of bursting the flues or melting the bricks.

The following experiment, by Gallon, made with a view to ascertain the difference in the quality of bricks differently manufactured, deserves to be generally known. A certain quantity of the earth prepared for moulding into bricks was taken for the experiment; at the end of seven hours, it was moistened and beaten for the space of thirty minutes. The

next morning the same operation was repeated for an equal length of time; in the afternoon it was again beaten for fifteen minutes. Thus this earth had not only been worked for an hour and a quarter longer than usual, but at three different times; the consequence was, that its density was increased; for a brick made of it weighed five pounds eleven ounces, while another brick made in the same mould, of the earth that had not received this preparation, weighed only five pounds seven ounces. The two sorts of bricks were dried in the air, for the space of thirteen days; they were then burnt with others, without any particular precautions, and when they were taken from the kiln, it was found that the bricks made of the earth which had been most worked, still weighed four ounces more than the others, each having lost five ounces by the evaporation of the moisture. They differed also very remarkably in strength; for on placing them with the centre on a sharp edge, and loading the two ends, the bricks formed with the well-tempered earth were not broken with a less weight than sixty-five pounds, or one hundred and thirty pounds in all; while the others were broken with thirty-five pounds at each end, or seventy pounds in the whole. That the quality of bricks should be improved, by bestowing more labour upon the preparation of the earth, will hardly excite surprise, though the degree of the improvement, as just stated, may certainly be considered remarkable; but there is another mode of strengthening these artificial stones, still more extraordinary, and not so easily to be accounted for. Goldham observes, that bricks which have been once burnt, then steeped in water, and burnt again, become doubly strong. We know not that this observation, which is repeated without comment, by nearly all the writers who have occason to treat of this subject, will always be verified in practice, but it deserves attention, from the number and respectability of the writers who have contributed to give it currency.

When the earth is sufficiently prepared, it is brought to the bench of the moulder, who works the clay into the brickmould, which he has previously dipped in dry sand lying near him for the purpose; he then strikes off the superfluous soil with a flat smooth stick, which is dipped in water before it is used. The bricks, as they are delivered from the mould, are ranged on the ground, with a small interval between each; in piling row upon row, they are laid rather crosswise, and sand is thrown over them, to prevent their adhering to each other. As soon as they have acquired sufficient hardness to admit of handling, they are dressed with a knife, turned, and reset more open. A gang, consisting of six persons, will make twenty thousand bricks in the course of a week. The time required for drying

them necessarily varies with the state of the weather; if this be favourable, fourteen or sixteen days will often be sufficient. In showery weather, the piles are usually protected from its bad effects by some cheap covering, such as straw, or old light boards. In grounds not extensive, sheds are often erected.

When the bricks have been sufficiently dried in the air, they are burnt, which is done either in a kiln, or in a stack, technically called a clamp. The kilns are usually made large enough to burn twenty thousand bricks, being about thirteen feet long, ten feet broad, and twelve feet in height. The aperture is diminished by contracting the walls towards the top, where the area is about one-tenth smaller than below. The thickness of the walls should at least be a brick and a half. Bricks are burned in kilns with less fuel, and with greater uniformity and expedition, than in clamps. When they have been set or placed in the kiln, they are covered with pieces of bricks or tiles, and dried by kindling a gentle fire, which is kept up for two or three days, or till the smoke becomes light. More fuel is then added, and the mouth or mouths of the kiln are nearly closed with bricks and wet clay; as soon as the arches of the kiln look white, and the fire begins to appear at the top, they slacken the heat for an hour, and let all cool by degrees. This they continue to do, alternately heating and slacking, till the bricks are thoroughly burnt, which is usually effected in forty-eight hours.

The stacks or clamps are built of the bricks themselves. The foundation is commonly somewhat raised from the surrounding ground, and of an oblong form; the sides slant inwards a little towards the top; hence the clamp, in its figure, is a truncated pyramid. Flues, about the length of a brick in breadth, are made entirely through the clamp; they are about six feet apart when the burning is to be hastened, otherwise they are made about nine feet from each other. The arching of the flues is performed by laying the successive layers of bricks a little over the edge of those below them, till they nearly meet, and then a binding brick at the top finishes the arch. In every direction, the bricks are separated from each other by a stratum of coals and cinders. To facilitate setting fire to the clamp, a quantity of wood is laid with the coal in the flues. When the fire is kindled, if it burn strongly, or the weather is precarious, they plaster the outsides of the clamp with clay, and close the apertures of the flues. On the top of the clamp, a thick layer of breese (cinders) are uniformly laid. When the whole of the fuel is consumed, the manufacturer concludes that the bricks are sufficiently burnt. The operation requires from twenty to thirty days, according to the

quantity of fuel, the proximity of the flues, and the state of the weather.

The different kinds of bricks made in this country are, principally, place bricks, grey and red stocks, marl facing bricks, and cutting bricks. The place bricks and stocks are used in common walling; the marls are made in the neighbourhood of London; these are very beautiful bricks, of a fine yellow colour, hard, and well burnt, and in every respect superior to the stocks. The finest kind of marl and red bricks are called cutting bricks; they are used in the arches over windows and doors, being rubbed to a centre, and gauged to a height.

An acre of land, including the ashes mixed with the earth, is computed to yield about one million of bricks for every foot in depth. The brick mould is ten inches in length, and three in breadth, and the finished bricks are about nine inches long, four and a half broad, and two and a half thick. Different qualities of earth, however, produce bricks of different dimensions from the same mould; and even the same earth, in proportion as it is more or less wrought or burnt, exhibits similar results.

It is extremely probable that bricks, properly made, would prove superior in durability to almost every kind of stone. In Holland, the streets are every where paved with a hard kind of bricks, known by us under the name of clinkers, which are often imported into this country, and used for paving stables and court yards; and houses in Amsterdam which have stood more than two centuries, so far from being decayed, appear perfectly fresh, as if new.

The numerous patents which have been granted for the making of bricks, appear to have had improvements in the formation of the article for their principal object, without much regard to the materials of which it is composed. Cartwright's patent, the exclusive privilege conferred by which has now expired, is perhaps one of the most important. His improvement consists in giving bricks such a shape or form that they shall mutually lock or cramp each other. The principle of his invention may be understood, by supposing the two opposite sides of a common brick to have a groove or rabbet down the middle, a little more than half the width of the side of the brick in which it is made; there will then be left a shoulder on each side of the groove, each of which shoulders will be nearly equal to one quarter of the width of the side of the brick, or to one-half of the groove or rabbet. A course of these bricks being laid shoulder to shoulder, they will form an indented line of nearly equal divisions; the grooves or rabbets being somewhat wider than the two adjoining shoulders, to

allow for mortar, &c. When the next course comes on, the shoulders of the bricks which compose it, will fall into the grooves of the first course; and the shoulders of the first course will fit into the grooves or rabbets of the second, and so on. This configuration of the bricks is to be preferred, as it is perfectly simple; but the principle will be preserved by whatever form of indenture they lock or cramp each other. For the purpose of turning the angles, it may be expedient to have bricks of such a size and shape as to correspond with each wall respectively; though this is not absolutely necessary, as the grooves in the bricks of each wall, where they cross or meet each other, may be levelled, and the bricks lap over as in the common mode. For the purpose of breaking the joints in the depth of the wall, bricks will be required of different lengths, though of the same width. Buildings constructed with bricks of this principle, will require no bond timber, one universal bond running through and connecting the whole building together; the walls of which can neither crack nor bulge out, without breaking through the bricks themselves.

When bricks of this form are used for the construction of arches, the sides of the grooves or rabbets, and the shoulders, should be the radii of the circle of which the intended arch is to be the segment. In forming an arch, the bricks must be coursed across the centre on which the arch is turned, and a grooved side of the bricks must face the workman. It may be expedient, though not absolutely necessary, in laying the first two or three courses at least, to begin at the crown and work downwards. The bricks may be either laid in mortar, or dry, and the interstices afterwards filled and wedged up, by pouring in lime putty, plaster of Paris, grouting, or any other convenient material, at the discretion of the workman or builder. Arches on this principle, it is stated, having no lateral pressure, can neither expand at the foot, nor spring at the crown, consequently they will want no abutments, requiring only perpendicular walls to be let into, or to rest upon; and they will want no incumbent weight upon the crown to prevent their springing up, a circumstance often of great importance in the construction of bridges. Another advantage attending this mode of arching is, that the centres may be struck immediately; so that the same centre (which in no case need be many feet wide, whatever may be the breadth of the arch,) may be regularly shifted as the work proceeds. But the greatest and most striking advantage attending this invention, is the absolute security it affords (and at a very reasonable rate) against the possibility of fire; for, from the peculiar properties of this arch, requiring no abutments, it may be laid

upon, or let into, common walls, no stronger than what are required for timbers, of which, precluding the necessity, it saves the expense. A more particular account of this invention, illustrated by two plates, may be seen in the third volume of the "Repertory of Arts and Manufactures."

In 1798, Francis Farquharson, of Birmingham, obtained a patent for making bricks and tiles by machinery, and indeed the use of horse power, in working the clay, is now very common.

Whitmore Davis, of Castle Comber, in the county of Kilkenny, Ireland, observed some persons in the vicinity of a colliery, to employ a mortar, for the backs of their grates, which in a short time became very hard. This substance he found, on inquiry, to be what miners term *seat-coal*, or that fossil which lies between coal and the rock. It has been examined by Kirwan, who is of opinion that it will, when mixed with a due proportion of clay, produce a kind of bricks, capable of resisting the action of fire, and consequently well calculated for furnaces, or similar structures. The discovery of the use of this substance is considered important, and it is further observed, that seat-coal, properly prepared, will answer every purpose of tarras, for buildings beneath water.

In building, a considerable waste of time arises from the necessity of making bricks less than the common size, to suit particular situations. Nor is the waste of time the sole loss; in attempting to divide a brick, especially in the direction of its length, one half of it is generally reduced to useless splinters; but bricks have lately been made, which in their soft state were nearly cut through by pressing a wire upon them; they can then be divided by a single blow: a proportion of them along with the common sort, produces on the whole a saving of some moment.

It is of considerable importance to examine clay before it is made into bricks, in order to ascertain whether any addition can be made to it which will improve its quality. According to the observation of Bergman, the proportion of sand to be used with any clay, must be greater, the more such clay is found to contract in burning, but the best clays are such as require no sand. This illustrious chemist recommends the following mode of analysis to manufacturers:. Nitric acid poured upon unburned clay, detects the presence of lime, by producing an effervescence. Calcareous clays, or marls, are often the fittest materials for making bricks. In the next place, a lump of clay, of a given weight, is to be diffused in water by agitation. The sand will subside, and the clay

remain suspended. Other washings of the residue will carry off some clay, and by due management in this way, the sand, or quartzose matter, may be had separate. Nitric acid by digestion will take up the lime from a part of the clay, previously weighed, and this may be precipitated by volatile alkali. The clay, the sand, and the lime, may thus be well enough ascertained by weight, so as to indicate the quantity of sand or other material requisite to be added, in order to form that compound, which, from other experiments, may have been found best adapted to produce good tiles and bricks. An examination with the microscope will shew whether the sand contain feld spar or other stones of known figure.

Paving tiles are a long flat kind of brick, used for laying the floors of kitchens, dairies, cellars, &c. Two or three sizes of them are generally made; the least of English manufacture are about the same length and breadth as common bricks; the largest are about twelve inches square; a middle size, about nine inches square, is also in common use. The thickness of all the sizes of paving tiles is only about an inch and a half. They are made of the strongest kind of clay, and well burnt. Paving tiles or bricks look the best when laid diagonally.

The most common tiles for roofs, are those called pan tiles, which are thirteen inches long and eight broad, and about half an inch thick; they are curved in the direction of their length, so that their transverse section is a figure of contrary curvature, like the letter ∽ ; the hollow of one side serves as a channel for the rain, and for that purpose is made of greater radius than the other, which is employed to overlap the edge of the adjoining tile. The tile, at the upper end of its under surface, has a knob, by which it is hung to the lath. Tiles constitute a very heavy covering, and require the laths by which they are supported to be proportionately strong. The laths, for pan tiles, are about three-quarters of an inch thick, and an inch and a quarter broad; they are generally made of deal. The other sorts of tiles are chiefly plain tiles, hip tiles, and ridge tiles; the latter resemble half a hollow cylinder, and are laid on the ridges of houses. Ridge tiles are required by statute to be thirteen inches in length, and six inches and a half in breadth.*

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* *Brick-water,* or water impregnated with the contents of bricks or tiles, is possessed of properties so remarkable, and at the same time so pernicious in their effects, when used for culinary purposes, that we cannot refuse a place to

In Holland, they frequently glaze their roofing tiles, which increases their durability, but considerably enhances the price of them. The early destruction of unglazed tiles is occasioned by the moisture they imbibe; for when the water has sunk into them, they break with* the action of the frost. Sonini has, however, discovered an excellent preventive of this effect, nearly equal to glazing, and very cheap: he directs us to brush over the tiles with tar, after they have been well warmed in the sun. Tiles which have been cracked by the frost, may be preserved from the further influence of the same cause, by the like application.

By stat. 2, Geo. 2, cap. 15, any two, three, or more persons, appointed by the justices of the peace, are empowered, within fifteen miles of London, to go in the day time, into any grounds, sheds, or places, where any clay or earth shall be digged or digging, for bricks or pan tiles, or any bricks or pan tiles shall be making or made for sale, and there to search for, view, and inspect the same, &c.—Offenders to forfeit twenty shillings for every thousand of unstatutable bricks, and ten shillings for every thousand of such tiles; one half of the fine to the prosecutor, and the other to he poor of the parish in which the offence shall be committed.

By stat. Geo. 2, cap. 22, there may be mixed with the brick earth any quantity of sea-coal ashes, sifted or skreened through a sieve or skreen half an inch wide, and not exceeding twenty loads to the making of 100,000 bricks, each load not exceeding thirty-six bushels. And breese may be mixed with coal in the burning of bricks in clamps for sale, &c. Stock bricks and place bricks may be burned in the same clamp, provided that the stock bricks be set in one distinct parcel, and not mixed and surrounded with place bricks.

By stat. 10, Geo. 3, cap. 49, the earth for making bricks must be turned at least once after it is dug, before it is made into bricks.

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* the following curious experiment made by Dr. Percival, and stated in the first volume of his Essays. He steeped two or three pieces of common brick, four days in a basin full of distilled water, which he afterwards decanted off, and examined by various chemical tests. It was not miscible with soap; struck a lively green with syrup of violets, became slightly lactescent by the volatile alkali, but entirely milky by the fixed alkali, and by a solution of sugar of lead. No change was produced on it by an infusion of tormentil root. Hence the Doctor justly concluded, that the lining of wells with bricks, a practice very common in various places, is extremely improper, as it cannot fail to render the water hard and unwholesome.

By 17, Geo. 3, cap. 42, stock and place bricks made for sale, shall, when burnt, be not less than eight and a half inches long, four inches wide, and two and a half inches thick.

By 43, Geo. 3, cap. 69, (consolidating the excise duties,) every thousand of bricks made in Great Britain, not exceeding ten inches long, three inches thick, and five inches wide, is liable to a duty of *five shillings*, and if exceeding these dimensions, to *ten shillings*: and every thousand of bricks made in Great Britain, and smoothed or polished on one or more sides, not exceeding the superficial dimensions of ten inches long, and five inches wide, is subject to a duty of *twelve shillings*; and if such bricks exceed these dimensions, to the duty on paving tiles. The said duties are to be paid by the makers. An additional duty of *tenpence* per thousand was imposed on bricks and tiles in 1805.

Of the Tools used in Bricklaying.

The *brick trowel*, which is used for taking up and spreading the mortar, is also used for cutting the bricks to any required size, and should therefore be made of the best steel, and well tempered.

The *hammer* used by the bricklayer, is adapted either to strike a blow, or to divide the bricks, as may be required in cutting a hole through a brick wall, or other operations. One end of the head of it has therefore a face similar to that of any common hammer, and the shape of the other end resembles that of a carpenter's axe, though far narrower in proportion to its length. The handle is inserted much nearer the face of the hammer, than the other extremity or edge. Another kind of hammer, often employed in taking down brick-work, differs from the above only in having, instead of the axe part, nearly the shape of an adze, but not so broad for its length; hence it may be driven with facility between bricks to separate them.

The *plumb-rule* is similar to that used by carpenters and other artizans. It consists of a well-seasoned board, the length of which should at least be four feet; its thickness and breadth are not very material, provided they be sufficient to prevent its warping. Down the middle of one of the broad surfaces of the board is drawn a straight line, and at one extremity in this line, is attached a small cord with a weight at the lower end. If the long narrow sides of the rule be perfectly straight and parallel with each other, and the line is equidistant from the arris on each side of it, the plummet being hung in this line, will form a correct instrument. Either of the long narrow

sides of this rule is applied to the wall, so that the plummet and its cord may face the workman, who, by frequently using it, is enabled to carry up his wall perpendicularly. If in any of these trials, he observes that the cord of the plummet does not coincide with the line on the rule, he sets the bricks further in or out, as may be required to rectify the error, taking care to do it while the mortar they are set in is yet wet.—As the plummet is not made to hang below the rule, a hole is cut in the latter, to allow the cord to hang straight.

The *level* employed by the bricklayer, is also similar to that of the carpenter. It is of various lengths from six to twelve feet. If one end of the plumb-rule above-mentioned were joined at right angles to the middle of the long narrow edge of another board of the same thickness, but about double its length, it would become a level, the lower edge or side of the piece thus added to the rule, becoming the surface placed on walls, particularly at window sills and wall-plates, to ascertain whether they are horizontal or not. To try the correctness of a level, place it vertically, that is, in the position in which it is used, upon any flat surface, or merely place each end of the bottom edge upon a block of wood, and raise or lower the supports till the cord of the plummet exactly coincides with the line on the perpendicular rule or limb of the instrument. When this is observed, reverse the ends, and if the same coincidence then takes place, the level is true; but if it does not, the bottom must be planed, till the trial will succeed. The perpendicular and horizontal parts of the level are not only fastened together by mortise and tenon, but, for greater firmness, and to prevent warping, two braces are added, which extend, in a slanting direction, from the horizontal piece nearly to the top of the perpendicular one.

A *large square* is employed in setting out the sides of buildings at right angles; and a *small square* for trying the bedding of bricks, and squaring the soffits across their breadth.

A *bevel* is required for drawing the soffit line on the face of bricks.

The *rod*, for measuring, is either five or ten feet long; the feet are divided by notches, and one of those next the extremity of the rule, is divided into inches. Dimensions may be more expeditiously ascertained with the rod than with a pocket rule; but bricklayers are generally provided with a measuring *tape*, which is coiled up by its winch into a cylindrical box, of such small dimensions, as to unite a more convenient portability than the pocket rule, with greater dispatch in the general operations of measurement, than can be obtained by the use of the rod.

The *jointing-rule*, employed in running the joints of brick-work, is eight or ten feet long, and four inches broad. When designed for the use of two bricklayers, the latter length is employed.

The iron tool used along with the jointing-rule, to mark the joints of brick-work, is called a *jointer;* its form is nearly that of the letter ʃ, though its flexure is not in proportion so considerable.

The *raker* has its use designated by its name. It is employed to rake or scrape loose and decayed mortar out of the joints of walls, the appearance of which is intended to be improved by pointing them afresh. The raker is made of iron, pointed with steel, and at about one-fourth of its length from each extremity, it is bent to a right angle, so that it would resemble a Z, if the stroke connecting the top and bottom of that letter were perpendicular instead of slanting.

The *hod* is an angular wooden trough, closed only at one end; so that it resembles the half of a rectangular box divided in such a manner as to consist of two entire sides and one end. From the middle of the angular ridge formed by the meeting of the two sides, proceeds a pole or handle about four feet long; and so much of this ridge as lies between the handle and the end piece, is covered with a cushion of several thicknesses of leather, or leather stuffed with wool. In this utensil, the labourer carries upon his shoulder the bricks and mortar with which he supplies the bricklayer; the cushion takes off the sharpness of the ridge, and by means of the handle, he can support it without difficulty, either in walking on level ground, or ascending a ladder. It is customary to sprinkle the inside of the hod with clean dry sand, before it is filled with mortar, which is thereby prevented from adhering to the wood.

A *cord* or *line*, to serve as a guide in laying the courses of bricks exactly straight, is stretched close to the wall, and removed at the proper intervals as the work advances. This line, to afford the means of stretching it wherever it is wanted, is fastened to two pointed iron pins, called the *line vins*, one being attached to each end of it.

The bricklayer's *rammer* differs not from the pavier's. If the ground intended for a foundation is deemed not sufficiently solid, it is compressed as much as possible by this tool, a due attention to the use of which will prevent fractures that may endanger the building.

The *iron-crow* and the *pick-axe*, are useful assistants to the bricklayer, of obvious utility; being sometimes employed in conjunction, and sometimes alone, in digging, breaking through

walls, raising heavy bodies out of the ground, and similar operations.

The *compasses* for traversing arches, and the *grinding-stone* for sharpening tools, scarcely, perhaps, require to be mentioned.

The cutting and management of bricks for the construction of gauged arches, add the following tools, besides the small square and bevel above-mentioned, to the catalogue belonging this trade:

The *chopping block*, is made out of any piece of wood which happens to be at hand, set or fixed with sufficient stability for axing the bricks upon. Its height may be about thirty inches; the area of its upper surface is generally inconsiderable; if six or eight inches square, it is sufficiently large for one man to work at. When several men are at work, it is better that they should have separate chopping blocks than a single large one, unless the single one be very firmly fixed, so that the vibrations communicated by any of the workmen, may not inconvenience the rest, and unless also its dimensions be increased in a much greater proportion than the number of hands.

The *banker*, is the appellation which designates a large bench, upon which the bricks for arch-work are rubbed and gauged. It is from two to three feet in breadth, and from six to twelve feet in length, according to the number of men it is intended to accommodate, or the dimensions of the timber which happens to be at hand or most cheaply obtainable. The banker is generally made thirty or thirty-two inches high: as it is not necessary for it to be very thick, an old door may be converted into one, supporting it by four or five posts or piers, and for greater steadiness setting one edge against a wall.

The *camber slip* is a piece of board cambered or made convex on one or both edges, but not confined to any particular length, breadth, or thickness, though the latter dimension is generally about half an inch. It is employed as a ruler. When only one edge is curved, it rises about one inch in six feet, for drawing the soffit lines of straight arches: when the opposite edge is curved, it rises only about half an inch in six feet, and is used to draw the upper side of straight arches. This small convexity is an allowance for the settling of the arch, which many disregard, and therefore make the upper side of the arches in question straight. When the bricklayer has drawn his lines with the camber slip, he hands it to the carpenter, who by it forms the centre to the curve of the soffit. To prevent the necessity of having many camber slips, one is made large enough for the widest aperture likely to be arched.

The *mould* is used to obtain the proper form of the brick, that it may be reduced to the requisite taper, one edge of the

mould being brought close to the bed of the brick previously squared. There is a notch in the mould for every course of the arch.

The *scribe* is any piece of iron, such as a large nail or the like, ground to a point, for the purpose of marking the bricks where they are to be cut.

The *tin-saw* is used in cutting the bricks about the eighth of an inch deep, at the lines marked with the scribe, so that an entrance may be made for the brick-axe, and that they may be reduced to the proper form for arches, without splintering or jagging their edges. The false joints are also cut with this instrument.

The *brick-axe* is used for reducing bricks to the saw cuttings and lines drawn by the scribe. The subsequent labour of rubbing the bricks is shortened in proportion to the dexterity shown in the management of the axe.

When the bricks have been cut with the requisite exactness by the axe, they are taken to the *rubbing-stone,* upon which they are rubbed smooth. The rubbing-stone is generally fixed upon a bed of mortar at one end of the banker. To keep it tolerably level, the bricks should be rubbed equally on every part of it, and in different directions; it should not therefore be so large as to prevent the workman from easily reaching over it, on whatever side of it he stands: about twenty inches in diameter is a convenient size. If the grain of it is not sharp enough to reduce the brick with the necessary expedition, sand may be used. The headers and stretchers in returns, which are not axed, are also dressed upon the rubbing-stone.

The *bedding-stone* is a marble slab, about ten inches broad, and twenty inches long, with one flat surface, which is used to try whether the rubbed surface of the brick be straight, so as to fit upon the leading skew back, or leading end of the arch.

The stone upon which bricks cut with curved surfaces are rubbed, is called a *float-stone,* which must itself necessarily be curved in the reverse form, though of a radius equal to that intended for the brick.

Of Foundations

Foundations are either natural or artificial; natural, where the ground is rocky or good; artificial, when, from its boggy, sandy state, or from its having been lately dug up, piling, or some other precaution, must be resorted to, for the support of the building. Appearances are so often deceitful, that the prudent builder will never depend upon them, but will examine the ground intended for a foundation with the utmost attention. If the ground shake on being struck with the rammer, the

nature of it must be ascertained by piercing it with a well-digger's borer. Having found how far the firm ground is beneath the surface, the loose or soft parts must be removed, if not very deep: the excavations made on these occasions, should widen upwards, and their sides be cut in the form of steps: by which means a firmer bed will be obtained for the wall, than if the sides of the trenches were simply inclined planes.

Palladio directs the ground for the foundation to be penetrated to a sixth part of the whole height of the building, unless there be cellars, in which case he recommends digging deeper. It is a good rule to make the foundation double the breadth intended for the superincumbent wall, and the con traction of it should be made alike on both sides.

If the earth is very unsolid, piles, close to each other, and long enough to reach the good ground, must be driven in. The thickness of these piles should not be less than one-twelfth of their length; they should be made to present as even a surface as possible, and should then be covered with planks. It is a curious fact, that dry, straight-grained piles, may be driven much further by the same force, than if they be made of wood in an opposite state.

When the infirmity of the ground is uniform, but not very considerable, it may be made good by laying pieces of sound oak about two feet apart, across the breadth of the trench in which the wall is to stand, and when these have been firmly bedded and rammed down, planks of the same timber, or of pitch pine, (which is equally as durable in such situations,) must be laid down and spiked upon them. The planks should be half a foot wider than the base of the foundation wall. Ground of this description may also be made good by ramming large stones upon it closely together, and extending in breadth about a foot on each side of the wall. Upon the first course of stones, another course, rather narrower, may be laid, taking care, as in walling generally, to make the joints of one course fall on the middle of the stones in the other.

If the ground be found defective in one place and good in another, the unequal settlement which would be the inevitable consequence of building upon it in such a state, may be prevented by a plan which is now becoming daily more common, and which, if carefully executed, is always successful. It consists in the use of arches, either inverted or suspended, according to circumstances, which we shall now advert to.

When the soft parts of the ground are under the apertures only, inverted arches are to be turned under such apertures, in the manner represented by fig. 1, pl. 1. By this means the

advantage of one continued base is obtained, for the piers cannot sink without carrying the arches, and consequently the ground upon which they stand, along with them. The whole building will therefore sink equally, and no fracture of the walls will ensue. So much is the use of inverted arches under apertures approved, that they are considered indispensable in all buildings of considerable weight or consequence, even when the ground is not found to be defective. It is sufficiently obvious, that the walls of all buildings, the base of the foundation of which is not actually laid upon the bare, solid rock, will sink a little; and as the pressure of the piers is incomparably greater than that of the low piece of walling under the apertures, the risk is extreme, that the resistance of the ground against this low walling will not allow it to sink with the piers, and consequently the fracture of the wall, and probably the breaking of the window sills, will be the consequence. The inverted arches prevent these bad effects; and as they have so important a service to perform, they should be thrown with the greatest care, closely jointed, and their depth at least equal to half their width.

When the reverse of the preceding case occurs, that is, when the solid parts of a foundation are only to be found under apertures, then piers must be built in these places, and arches suspended between them, as represented by fig. 2. It is best to make the middle of the pier rest upon the middle of the summit of the arch. If the pier does not cover the arch, the narrower it is the greater should be the curvature of the latter at the apex. When arches are used in this way, the intrados ought to be clear, that they may have their full effect. The uniform resistance of the ground upon which the piers are erected, is also of greater importance than even its perfect hardness; for if it resist uniformly, the building will sink in every part alike, and remain uninjured.

When wood is laid in the trench of a foundation, the first course of stone or brick should be laid as close as possible, without mortar, which injures the timber. If there be any difference in the quality of the bricks, the strongest and closest, which are least liable to imbibe moisture, should be selected for foundation work.

Of Cements.

The bricklayer being provided with tools, with bricks, and having prepared the trenches of his foundation for walling, finds himself in immediate want of mortar or cement, a subject which next claims our consideration.

The nature and best methods of preparing calcareous cements, have been investigated by Dr. Higgins, with great ability and success. He has advanced the most satisfactory proofs, founded upon analysis, that the Romans, whose mortar or cement, after a lapse of two thousand years, instead of being decayed, has become as hard as the stones it binds together, possessed no uncommon secret, which we are unable to discover. His publication first appeared in 1780, and is evidently the production of a liberal and intelligent mind. He struck into a path with which we were but little acquainted, though the knowledge of it is of very considerable importance to the public collectively, as well as to individuals: for it is certainly lamentable to observe public or private edifices, insecure, or prematurely mouldering away, from the ignorance or disregard of a few particulars, which might not only be observed with ease, but, in many instances, with a diminution of the original expense. The Doctor's conclusions, which were drawn from innumerable experiments, constitute a great portion of the best part of our knowledge on this subject at the present time; but though so many years have elapsed since they were communicated to the public, they are far from being yet generally known, and consequently are not reduced into general practice.

Such is the neglect shewn on this subject, that the timbers of our houses last longer than the walls, unless the mouldering cement be frequently replaced by pointing. The following directions, for preparing durable mortar or stucco, contain the result of the Doctor's experience, and have been attended to with remarkable success.

Sharp sand free from clay, salts, calcareous, gypseous, or other grains less hard and durable than quartz, is better than any other. When a coarse and a fine sand, corresponding in the size of their grains, to the coarse and fine sand hereafter described, cannot be easily obtained native, the following method of sorting and cleansing it must be resorted to. Let the sand be sifted in streaming clear water, through a sieve which will allow all grains not exceeding one-sixteenth of an inch to pass through, and let the stream of water be regulated so as to wash away the very fine parts of the sand, the clay, and every other matter lighter than sand. The coarse rubbish left on the sieve must be rejected. The sand which subsides in the receptacle must then be further cleansed and sorted into two parcels, by the use of a sieve which allows no grains to pass but what are less than one-thirteenth of an inch in diameter. That part which passes through this sieve, we shall call fine sand, the remaining portion, coarse sand. These

separate portions may then be dried in the sun, or by means of a fire.

That sort of lime must be chosen which heats the most in slaking, and slakes the quickest when duly watered; which is the freshest made, and has been the closest kept, which dissolves in distilled vinegar with the least effervescence, and leaves the smallest residue insoluble, and in this residue the smallest quantity of clay, gypsum, or martial matter. Put fourteen pounds of the lime chosen according to these important rules into a brass wire sieve still finer than the last mentioned. Slake the lime by alternately plunging it into and raising it out of a butt of soft water; reject all the matter which does not easily pass through the sieve, and use fresh portions of lime in a similar manner, until as many ounces of lime have passed through the sieve as there are quarts of water in the butt. This is the lime-water, which contributes materially to the excellence of the stucco. As soon as a sufficient portion of lime has been imparted to it, it should be closely covered until it becomes clear, and then be drawn off, by wooden cocks, placed at different heights as the lime subsides, without breaking the crust formed on the surface. The freer the water is from saline matter, the better will this liquor be. Lime-water must be kept in air-tight vessels till the moment it is used.

Slake fifty-six pounds of lime chosen as above directed, by gradually sprinkling on it the lime-water. Sift the slaked part of the lime immediately through the last mentioned fine brass-wire sieve; the lime which passes must be used instantly, or kept in air-tight vessels, and the rest rejected. This finer, richer part of the lime, may be called purified lime. It is always advisable to sift the lime *immediately* after the slaking, otherwise much of the ill-burnt lime and heterogeneous matter which it may contain, will pass through the sieve.

The materials of the cement being thus prepared, take fifty-six pounds of the coarse sand, and forty-two pounds of the fine sand; mix them on a large plank of hard wood placed horizontally; then spread the sand so that it may stand to the height of six inches with a flat surface on the plank, and wet it with lime-water, of which so much must be allowed to flow away off the plank as the sand in the condition described cannot retain. To the wetted sand add fourteen pounds of the purified lime in several successive portions, mixing and beating them up together with the instruments generally used in making fine mortar. Then add fourteen pounds of bone-ashes in successive portions, mixing and beating all together. The quicker and more perfectly these materials are mixed and beaten together, and the

sooner the cement thus formed is used, the better it will be. As this cement is shorter than mortar or common stucco, and dries sooner, it ought to be worked expeditiously in all cases, and in stuccoing it ought to be laid on by sliding the trowel upwards on it. The materials used along with it in building, or the ground on which it is laid in stuccoing, ought to be well wetted with the lime-water, at the instant of laying it on; and when the cement requires moistening, lime-water should always be used.

The proportions above given are intended for a cement made with sharp sand, for incrustation in exposed situations, where it is necessary to guard against the effects of hot weather and rain. In general, half this quantity of bone-ashes will be found sufficient; and although the incrustation in this latter case will not harden deeply so soon, it will be ultimately stronger, provided the weather be favourable.

When a mortar or cement of a fine texture is required, take ninety-eight pounds of the fine sand; wet it with the lime-water, and mix it with the purified lime and the bone-ash in the quantities and in the manner above described, with this difference only, that fifteen pounds or thereabouts of lime are to be used instead of fourteen pounds, if the greater part of the sand be very fine. This cement is suitable for the last coating of any work intended to imitate the finer grained stones; but it may be applied to all the uses of the first mentioned composition.

When a mortar or cement is required, which shall be still cheaper and more coarsely grained, much coarser sand than the coarsest sort already spoken of may be made use of; for the coarser the sand, the less the proportion of lime which will be required. For example, of the coarsest sand alluded to, take fifty-six pounds; of the coarse sand which passes through the meshes of a sieve one-sixteenth of an inch in diameter, twenty-eight pounds; and of the fine sand, fourteen pounds; and after mixing these and wetting them with lime-water, in the manner already described, add fourteen pounds, or somewhat less, of the purified lime, and then fourteen pounds, or somewhat less, of the bone-ash.

When these cements are intended to be white, white sand, white lime, and the whitest bone-ash, are to be chosen. Grey sand, and grey bone-ash, formed of half-burnt bones, are to be chosen to make the cement grey; and any other colour may be obtained either by chusing coloured sand, or by the admixture of the necessary quantity of coloured talc in powder, or of coloured vitreous or metallic powders, or other ingredients of a similar nature.

These cements are applicable in forming artificial stone, by making alternate layers of the cement and of flint, hard stone, or brick, in moulds of the figure of the intended stone; the stones thus formed being exposed to the open air to harden, but not exposed to rain till they are almost as strong as fresh Portland stone. They may be made very hard, and beautiful, by soaking them, after they are thoroughly dry, in the lime-water, and repeating this process several times at distant intervals. Incrustations, also, are greatly benefited by the application of lime-water, the entrance of which is facilitated by the use of bone-ashes in the cement.

When any of the above cements are intended to be used for water-fences, two-thirds of the prescribed quantity of bone-ashes are to be omitted, and an equal measure of powdered terras used instead; and if the sand employed be not of the coarsest sort, more terras must be added, so that the terras shall be by weight one-sixth part of the weight of the sand.

When a cement is required of the finest grain, or in a fluid form, so that it may be applied with a brush, for the purpose of smoothing and finishing the stronger crustaceous works, or for washing walls to a lively and uniform colour, the fine powder of calcined flints, or the powder of any quartzose or hard earthy substance, may be used in the place of sand; but in a quantity smaller as the flint or other powder is finer; so that the powder shall not be more than six times the weight of the lime, nor less than four times its weight. The greater the quantity of lime within these limits, the more the cement will be apt to crack by quick drying, and *vice versa*. For washing walls, the cement should not be made thicker than new cream, and should be laid on briskly with a brush, in dry weather. Fine yellow ochre is the cheapest colouring ingredient for such a wash, when it is required to imitate Bath stone, or the warmer white stones.

Where sand cannot be procured, any durable stony body, or baked earth grossly powdered, and sorted as if it were sand, may be used, measure for measure, but not weight for weight, unless the same bulk of the gross powder be the same as that of sand. But all substitutes for pure siliceous sand, are imperfect in proportion as the particles of which they are composed, are less hard than those of that material. The scrapings of roads, which consist principally of powdered calcareous stone, the old mortar and other rubbish from ancient buildings, have often been more strongly recommended than they deserve. These, and all muddy, soft, minutely divided maters, require a large proportion of lime, and never possess the hardness and durability which belong to good mortar.

Use of lime-water—bone-ashes.—Sharp sand.

Sea sand, well washed in fresh water, is as good as any other *round* sand; but if used without being freed from salt, the mortar made with it is extremely liable to be damp.

The proportion of lime may be increased without inconvenience, when the cement or stucco is to be applied where it is not liable to dry quickly; and in the contrary circumstance, this proportion may be diminished. The defect of lime in quantity or quality, is best supplied, by soaking the work, at distant intervals of time, with lime-water. It is proper to mix hair with these cements, when employed for interior work.

The powder of almost every well dried or burnt animal substance may be used instead of bone-ash.

The bone-ashes facilitate the operation of plastering, by increasing the plasticity of the mortar into which they enter. They also render the mortar less liable to crack, and cause it to acquire more quickly that state in which it is not easily injured by unexpected rain. If employed in a less proportion than one-fourth of the lime, they are of little use, and if they exceed the lime in quantity they are injurious to the cement. Hence the use of them should be regulated according to the following circumstances: when the artist is more solicitous to secure an incrustation from the effect of hot weather, to finish it quickly, and to guard against rain, than to make it durable in the highest degree, he may use as much bone-ashes as lime; but when the season, exposure, and other circumstances, permit him to attend solely to the true excellence and duration of his work, he must use, in his best calcareous cements, only one part of bone-ashes for every four parts of lime. By these rules he may chuse intermediate quantities adapted to his purposes. The bone-ashes should not be in so coarse a powder as they are when used for cupels, yet they should by no means be levigated or ground to extreme fineness.

By *sharp* sand, is meant such sand as consists of grains with flat surfaces; these flat surfaces, when enveloped and cemented together by the lime paste, possess a much stronger cohesion than if the grains were globular.

The preceding method of making mortar or stucco differs, it will be perceived, from the common process in several essential particulars; among which, the purity and sorting of the sand, the use of lime-water, the newness of the lime, and the large proportion of the sand to the lime, ought to be particularly noticed. It may be useful to inquire into some of the causes of differences of practice so remarkable. When the sand contains much clay, or other impurities, the bricklayers find that the best mortar they can make, must contain about

one-half lime; and in consequence pronounce, without further investigation, half sand and half lime, to be the best composition. But with sand requiring so much lime, they never can make durable mortar, though of this fact it may be difficult to convince those who are little disposed to investigate causes. Too many artisans entertain an opinion that they have nothing new to learn which is worth notice; they are apt in effect to say, that having served an apprenticeship to their business they *ought* to know *something*; and thus, because they *ought to know something*, they seem to expect submission to their very errors. To such characters we speak not; to convince them is impossible, and therefore the attempt is folly. But those who consider the interest of their employers, and that the warmth, dryness, and salubrity of a house, so far as the building is concerned, is completely in their power, will not despise any hint which may extend their resources.

It is a common fault to build lime-kilns so high, that at the bottom of the cavity, the lime is ready perhaps eighteen hours before that in the upper part, and is greatly injured by its exposure to the draft of air passing through the fire. Lime-kilns ought to be made much broader and shallower than customary, with the cavity tapering upwards, and should terminate in a lofty flue, in order to accelerate the combustion, when required, by a quick current of air. Calcareous stones acquire in the most eminent degree the properties of lime, when they are slowly heated in small fragments of uniform size, until they appear to glow with a white heat, and this is continued until they become non-effervescent if steeped in an acid. The art of preparing lime consists chiefly in attending to these particulars. The whiteness of lime shews it to be free from metallic impregnation. Merely to keep lime dry is not enough to preserve it; it grows worse for mortar every day it is kept in heaps or untight casks, and is soon reduced nearly to the state of chalk. It may be greatly debased, without slaking sensibly, and such parts or fragments as fall to powder merely by exposure to the air are unfit for mortar. It has been found by experiment, that lime will absorb one-fourth of its weight of water, and yet remain perfectly dry. Bishop Watson found, that, upon an average, every ton of limestone produced eleven hundred weight, one quarter, and four pounds, of lime, weighed before it was cold; and that, when exposed to the air, it increased in weight daily, at the rate of a hundred weight per ton, for the first five or six days after it was drawn from the kiln. Hence those who have to fetch lime from great distances, may save even in point of cartage, by receiving it as it is taken out of the kiln.

Mortar which sets without cracking, whether this be owing to the due proportion of sand, or to the slow exhalation of the water from mortar containing less sand, never cracks afterwards, whatever its faults, in other respects, may be. As it is the lime paste, and not the sand, which contracts and produces fissures in drying, so the more sand there is in the composition, the less the cracks will be seen. Mortar which is liable to crack, becomes irreparably injured by frequent alternations of wetting and freezing; for the water imbibed by the smallest fissures, dilating as it congeals, loosens its whole texture. Where it is composed of seven parts of sorted sand, to one of lime, it is not disposed to crack.

That mortar may become indurated the soonest and in the highest degree, and operate the most effectually as a cement, it must be suffered to dry gently and set; the exsiccation of it must be effected by temperate air, and not accelerated by the heat of the sun or fire. It must not be wetted till after it sets; and afterwards it ought to be protected from wet as much as possible, until it is completely indurated; the absorption of carbonic acid must be prevented as much as possible till the mortar is finally placed and quiescent, and then it must be as freely exposed to the open air as the work will admit, in order to supply carbonic acid, and enable it sooner to sustain the trials to which mortar is exposed in cementitious buildings and incrustations. To shew more clearly how much our slight buildings are weakened by the agitations and percussions to which they are exposed, first in erecting the walls and settling the timbers, and then in driving those wedges to which the wainscots, mantle-pieces, and other ornaments, are fastened, we must observe, that the absorption of carbonic acid by mortar contributes nothing to the strength of it, if it enter before it is finally fixed in a quiescent state. A little experience is sufficient to teach us, that the same matter which assists in the induration of mortar, never serves to repair the fissures, or solution of continuity between the bricks and cement, which happens after it is set. When mortar is set, and before it is indurated, it may be easily severed from the bricks and crumbled; and for want of softness, it cannot bend into the fissures, or resume its former condition in any time. Hence by heavy blows, and in wedging, our walls must be greatly weakened; and the more so, as the houses are slight, quickly built, and hastily finished.

Nothing is more common than for bricklayers to keep their mortar some time exposed to the air in heaps, before they consider it proper to use; a practice which may perhaps be accounted for, if we consider that some portions of every kind of

lime used in this country, do not slake freely, by reason of their not being sufficiently burned, or of the admixture of gypseous or argillaceous matter; which portions, like marl, slake in time, though not so quickly as the purer lime. The plasterers, who use a finer kind of mortar, made of sand and lime, observe that their stucco blisters, if it contain small bits of unslaked lime, and as smoothness of surface is with them of more consequence than excessive hardness, they take care to secure the perfect slaking of their lime by allowing sufficient time for the imperfect parts to be penetrated by the moisture. The bricklayers, trusting, perhaps, more to the judgment of the plasterers, in this respect, than to their own, and considering it very convenient to slake a large quantity of lime at once, follow the same practice, without caring for or apprehending the real fact, that mortar is worse for every hour it is kept, and that they are taking such measures as will prevent it from ever acquiring that degree of hardness in which its perfection consists.

Among the circumstances which contribute to the speedy ruin of modern buildings, it may also be observed, that mortar made with bad lime, and a great excess of it, is used with dry bricks, and not unfrequently with warm ones. These immediately imbibe or dissipate much of the water, and as the cement approaches nearer to be dry, whilst it is still liable to be displaced by the percussions of the workmen, render it little better than equivalent to a mixture of sand and powdered chalk. To make strong work, the bricks ought to be soaked in lime-water, and freed from the dust with which they are commonly covered. By this means the bricks are rendered closer and harder, the cement, by setting slowly, admits the motion which the bricks receive when the workman dresses them, without being impaired, and it adheres and indurates more perfectly. This steeping of the bricks is an imitation of the practice of the plasterers, who always wet the wall before they commence their work, because they know the cement will not otherwise adhere. This ought to be done as long as the wall is thirsty, and lime-water is the most proper liquid they can use. The same advantage that attends the soaking of bricks, would attend the soaking of bibulous stones in lime-water.

Mortar made with sand containing one-seventh or one-eighth of fat clay, moulders in winter like marl; a circumstance which proves the propriety of freeing from clay the sand used in mortar. The washing performed for this purpose, will be found a very cheap operation, even in cities, if the water which carries off the clay be directed into a receptacle where it may be depurated by subsidence for repeated use.

Chalk lime may be easily prepared, so as to be fully equal if not superior to stone lime. The reason why this is not generally thought to be the case, probably is, that not being of so close a texture, it is sooner spoiled by the absorption of carbonic acid, when exposed to the atmosphere after it is made. A cask of chalk lime should therefore never be opened till the moment it is to be slaked, and the greatest expedition should be used in the slaking, and in the making and applying the mortar to use. In the quiescent air of a room, a pound avoirdupois of chalk lime, becomes two ounces and a half heavier in two days; and nearly the whole of this increase of weight, consists of the carbonic acid which it has imbibed from the atmosphere.

The fittest water for making mortar, is rain water; river water holds the next place; land water the next; spring water the last; sea water, and all waters noticed medicinally or otherwise, for their saline contents, ought never to be used for this purpose.

The compositions mostly used for stuccoing within doors, are incapable of hardening considerably, and when they are laid on the naked walls, soon become tarnished, unsightly, and inconvenient, by the damps which workmen call sweating. Sometimes these damps are occasioned by the bad construction of the walls, the joints of the facing bricks having become hollow by the decay of the mortar, or when the copings or gutters are defective: a damp by transpiration also occurs when the principal walls are stuccoed before they are dried, or when the materials of them are so spongy as to imbibe the rain, and the circulation of air is not sufficient to waft away the transuding moisture. The damp by condensation is also very common, and appears most on the closest incrustations, however perfect and old the walls may be. In such instances, the damp is owing to the closeness of the body, and a stucco pervious in a certain degree to air and moisture, will be free from it, as well as from the damp before mentioned. The customary mode of avoiding these damps, is to case the principal walls of houses with lathwork, on which the incrustation or plaster is laid at some distance from the wall. The narrowing of rooms and passages very perceptibly is the consequence of this method, besides its expense. Bone-ashes, each grain of which is tubulated in every direction, added to the stucco in half the quantity of the lime, are a preventive of these damps without lathwork.

The drying, induration, and texture of incrustations made on brick walls and other irregular surfaces, are always so far unequal as to exhibit visible traces which deform the work, and cannot be effectually obliterated by any known method so con-

venient as that of covering the first coarse incrustation, after it has dried, with another coat which may be made finer and smoother. Thus the expense of fine-grained, smooth, or coloured stucco, is rendered moderate; because the finer, or the colouring ingredients, may be reserved for the exterior coat, which will last for ages, if the cement be good

To tinge a cement sufficiently, of any colour which is not found in sand, so that the incrustation shall not be impaired, and that the colour shall be as durable as the cement, the most proper ingredients which can be used in lieu of sand, or of part of it, are coloured glasses or coloured stones of the hardest kind, beaten to coarse powder; the finer parts of which are to be washed away, not merely because they are injurious to the cement, but because they contribute very little to the intended colour.

Stucco made with the best proportions of lime, sand, and lime-water, is not bettered by painting as soon as it dries; as this covering retards the induration of it, by cutting off its communication with the air. It therefore renders it liable to be irreparably injured in wet weather, wherever the water can get behind the paint. If paint or oil ought ever to be applied on such stucco, it ought not to be laid on in less than a year after the incrustation is made. The painting and sanding of the common defective incrustations, contribute very little to their duration, although it hardens them at the surface; for it does not effectually prevent them from cracking, and it avails very little to paint the cracked stucco again, because cracked stucco is always hollow, as the workmen term it; that is, it parts from the wall in the parts contiguous to the cracks, sounds hollow on being struck with the knuckle, and falls off in a few years, if it be so thick and large in extent, as to break the adhering portions by its weight.

Mortar made of sand, water, and lime, whatever may be the proportions of the mixture, cannot be employed in aqueducts, reservoirs, and other aquatic buildings, unless sufficient time be allowed for its perfect induration before the admission of the water; but when mixed up with a quantity of terras, as already stated, it acquires the desirable property of hardening under water. A few additional remarks on this subject will perhaps be acceptable. A mortar made of terras powder and lime was used in water-fences by the Romans, and has been generally employed in such structures ever since their time. As it sets quickly, and when set is impenetrable to water, some people have hastily concluded that it is the best kind of mortar for any purpose. But it is found by experience, that mortar made of terras powder, whether coarse or fine, will

not grow so hard as mortar made with lime and sand, nor endure the weather so well; on the contrary, it is apt to crack and perish in the open air. Its efficacy in water-fences is experienced only where it is always kept wet, and seems to depend principally upon the property which the powder of terras has, in common with other argillaceous bodies, but in a higher degree, of expediting the crystallization of the calcareous matter, by imbibing the water in which it is diffused in the mortar, and of swelling, during this absorption, so much as to render the mortar impenetrable to any more water. It seems, also, that an acid of the vitriolic kind, which is contained in terras, contributes to the speedy setting of the cement, by reducing a part of the lime to the condition of gypsum. Terras is a volcanic production, consisting chiefly of clay and oxide of iron indurated together; and baked clay, reduced to powder, communicates to mortar properties of a similar kind.

Pozzolana is another volcanic production differing little from terras, as to the effect it produces in mortar. It is thrown out of volcanoes in the form of ashes, and is found in many countries, but most abundantly in the kingdom of Naples. The cement used by Smeaton, in the construction of the Eddystone light-house, was composed of equal parts by measure of lime and pozzolana; a mixture which was deemed the most suitable, as the building was exposed to the utmost violence of the sea; but a composition exceedingly proper for aquatic works in general, may be composed of two parts of lime, one of pozzolana, and three of clean sand.

It has lately been discovered, that manganese is a valuable ingredient in water-cements, if used in the following manner: mix together four parts of gray clay, six of the black oxide of manganese, and ninety of good limestone reduced to fine powder; then calcine the whole to expel the carbonic acid. When this mixture has been well calcined and cooled, it is to be worked into the consistence of a soft paste with sixty parts of washed sand. If a lump of this cement be thrown into water, it will harden immediately.

Of Brick Bond and Walling.

When a brick is laid so that its length is in the direction of the length of the wall, it is called a *stretcher;* and when its length crosses that of the wall, it is called a *header.*

The term *bond* is applied to any disposition of the bricks, by which the continuity, in a straight line, of the joints of a wall is interrupted. It is obvious that a bond may be adopted.

which will interrupt the rectilinear direction of both the horizontal and vertical joints of a wall; but in the two kinds of bond which have hitherto prevailed, the horizontal joints are continued in the same line round the whole building, and the vertical ones only interrupted. When the wall is only intended to be half a brick, or four inches and a half in thickness, the whole of the bricks are laid so as to form stretchers, that is, their length is laid in the direction of the length of the wall, and the bond is obtained simply by making the vertical joints in every course exactly opposite the middle of the bricks above and below. But when the wall is intended to be the length of a brick or more in thickness, it would be apt to split into parts if it consisted only of two or more walls separately bonded, as in the instance just mentioned of the half brick wall. The bricks, therefore, in thick walls, must be connected in their breadth as well as their length, and this is done according to two principal modes, one of which is called English, the other Flemish bond.

English bond consists of headers and stretchers crossing each other in separate horizontal courses. In Flemish bond, the headers and stretchers are placed alternately in the same horizontal course. Flemish bond is now so common, that hardly any other kind is to be seen; it is preferred, for its appearance, to the English, which is much superior in point of strength, and in facility of execution. Many attempts have been made to unite Flemish facings with complete bond, but without success. Some have laid thin slips of iron occasionally in the horizontal joints between the two courses; and others have laid diagonal courses of bricks in the core of thick walls, so as to cross each other at right angles in successive courses. By the latter means, though the bricks in the middle of the core have a strong bond, yet as they form triangular interstices with the bricks on each side, the bond of the whole wall is very incomplete. As the adjustment of the bricks in one course must depend on the course beneath, the latter, in making the Flemish bond, must be seen or recollected by the workman. The view of the joints of the under course is hindered by the mortar with which they are covered, to bed the bricks of the succeeding course upon, and it is perplexing for the workman to recollect the arrangement of them, so that he is in danger of making the joints frequently to correspond, and thus rendering the bond imperfect. In the old English bond, the outside of each course points out the proper disposition of the next, so that it is difficult for the workman to err.

The following plans of walls, in English bond, which well

deserve to be revived in this country, will render this subject more intelligible:

Fig. 3, pl. I. is the bond of a nine-inch wall. In order that two vertical joints may not run over each other, at the end of the first stretcher from the corner, after placing the return corner stretcher, which becomes a header in the face that the stretcher is in below, half the length of which it covers, a half brick is placed on its side, so that with the return corner stretcher, it extends six inches and three quarters, and thus a lap of two inches and a quarter is obtained for the next header; and the bond is continued by working up the wall with alternate rows of headers and stretchers mutually crossing each other. The half brick, or brick-bat, thus introduced, is called a *closer*, and must be divided, it will be understood, through its too broadest surfaces, in the direction of their length. The same effect might be obtained by the introduction of a three-quarter brick at the corner of the stretching course, for then when the corner header is laid over it, a lap of two inches and a quarter will be left at the end of the stretchers below for the next header, the middle of which, when laid, will be over the joint below the stretcher, and thus constitute a bond as before. The brick for the three-quarter bat, or closer, must be divided through its two broadest surfaces, in the direction of their breadth.

Fig. 4, represents the English bond of a brick and a half or fourteen-inch wall. Here the stretching course is so disposed, that the middle of the breadth of the bricks in the same layer or level, falls alternately upon the middle of the stretchers, and upon the joints between the stretchers.

Fig. 5, represents the English bond of a two-brick wall. To break the joints in the core of the wall, every alternate header, in the heading course, is only half a brick thick.

Fig. 6, represents the English bond of a wall two bricks and a half in thickness. The disposition of the bricks is similar to that of those in the last example.*

Fig. 7, part of the front of a wall in English bond, the unbroken side being the corner.

Fig. 8, the Flemish bond of a nine-inch wall. Two stretchers lie between two headers; and bricks being twice as long as they are broad, the breadth of the two stretchers is equal to the length of the header, which is the whole thickness of the wall. The dotted lines shew the disposition of the bricks in the second course.

Fig. 9, the Flemish bond of a brick and a half or fourteen-inch wall. On one side the bricks are laid as in the last example, and on the other side, half headers are placed oppo-

site the middle of the stretchers, and the middle of the stretchers opposite the middle of the end of the headers.

Fig. 10, another example of Flemish bond, for a wall of the same thickness as the last. Here the disposition of the bricks is alike on both sides of the wall, the tail of the headers being placed contiguous to each other, an arrangement that produces, in the core of the wall, square spaces, which must be filled with half bricks.

Fig. 11, part of the front of a wall in Flemish bond, reaching on one side to the corner.

Fig. 1, 2, 3, and 4, pl. II. exhibit plans of brick piers in Flemish bond. No. 1, in each figure, shews the bottom course, and No. 2 the upper course; or, which amounts to the same thing, No. 2 may be considered the lower course, and No. 1 will then be the upper one.

Fig. 1, is a pier, two bricks, that is, eighteen inches square; for in speaking of the thickness of a wall or pier as consisting of so many bricks, the length of a brick is always to be understood.

Fig. 2. a two and a half brick pier.

Fig. 3, a pier three bricks square.

Fig. 4, a pier three bricks and a half square.

Before we take leave of the subject of bond, we must remark, that a patent has very lately been taken out, by Moore and Co. of London, for a vertical bond, which is intended to supersede the use of the bond timbers introduced to secure the equal settlement of the wall. In case of fire, when the bond timbers of a house are consumed, the falling of the wall almost necessarily follows. The patentees, therefore, instead of these timbers, place rows of hard strong bricks perpendicularly in the middle of their walls, at short distances from each other in height as well as horizontal measurement, and they place each row of the perpendicular bricks in such a manner, as to be opposite the middle of the space between the row standing in the same position immediately above or below it. This plan for obtaining a vertical bond, seems new and ingenious, and is applicable, as indeed the patentees observe, to stone walls, as well as to those of brick.

Fig. 5, represents a straight arch, which is usually made the height of four courses of brick; but in considerable buildings, it may with great propriety be made the height of five courses. The manner of drawing the joints of a straight arch will be evident from an inspection of the figure. The joints of the arch-stones must all be made to lie in a direct line to the point C. The point C is easily obtained, as it is as far from

the points A and B, (which are separated by the whole breadth of the aperture,) as A and B are from each other. Hence the lines connecting A, B, and C, form an equilateral triangle. To key the arch in, it is usual to have a brick, and not the joint between two bricks, in the centre; and therefore the division of the arch must be managed accordingly. Though the brick in the middle tapers more in the same length than the extreme bricks, yet as the difference is very small, it is disregarded, from the great convenience of drawing all the bricks with the same mould. It may, however, be observed, that the real taper of the mould may be a medium between that required for the middle and that for either extreme distance. But whether this be done or not, the defect will not appear in practice.

Fig. 6, a scheme arch, one brick, that is nine inches high.

Fig. 7, a semi-circular arch, one brick high.

Fig. 8, an elliptical arch, one brick high, the top of which is divided into equal parts, and not the under side. It is struck from three centres, A, B, and C.

The arches delineated in the last three figures are often made a brick and a half, or even two bricks high; but for crowning the apertures of ordinary dwellings, the height of one brick is deemed sufficient, both for stability and appearance. In arches of one brick high, when the walls are only half a brick thick, it is evident there is no necessity for joints following the course of the arch in every alternate brick. Accordingly, these joints, in such walls, are generally false ones, being merely nicks of little depth cut with the tin-saw; and are made as a kind of decoration, in arches exposed to view, to give, when pointed along with the other joints, a more lively appearance. But when the walls are of one brick or a greater thickness, the joints in question must be real, and formed of two bricks disposed as headers, for the sake of bond.

Fig. 9, a plan of Tapper's improved method of groining. The improvement consists in raising the angles from an octagonal pier instead of a square one. By this means, the angles of the groins are strengthened by carrying the band round the diagonals of equal breadth, thus affording better bond to the bricks, which are usually so much cut away, that instead of giving support, they are themselves supported by the adjacent filling-in arches. Square piers are very inconvenient in cel lars, by hindering the turning of goods round their angles.

In different parts of the country, it will naturally be supposed that many differences of practice will prevail in the details of building. Several of these differences originate in local peculiarities of materials, of one kind or another; but there is

one, not belonging to this class, respecting which we might have expected to find a very general uniformity of practice. In London, and a wide district around, the scaffolding for the workmen, in erecting the walls of a building, is external; but in Liverpool, and several other parts of Lancashire, and adjacent countries, the scaffolding is wholly within the building, whatever may be its size or consequence. On the merits of either plan we shall not offer a decisive opinion; yet we may remark, that external scaffolding is not only the most expensive, but has an air of insecurity to the workman, and of incompactness, which is unpleasant to the observer, especially when he is aware that such cumbersome appurtenances may be dispensed with. In populous towns, or confined places, also, the encroachment of external scaffolding upon the street, is not a trifling inconvenience, particularly as the bricks and other materials must be at some distance beyond its limits, to prevent accidents. Interior scaffolding, on the contrary, being supported on the joists of each floor as the work proceeds, is erected with little trouble or expense, the workman marks his joints with as much ease and regularity as if he were at the outside, such a thing as a falling brick or splinter is hardly known, and the bricks and other materials, may, if necessary, be laid close to the wall, so as to occasion little inconvenience in the street.

To obtain the desirable requisite of dry walls, we have already observed, that the usual resort is the use of interior lathwork, and have adverted to the means of preventing this expense, by a proper composition of the mortar or stucco. Another expedient in common use, intended to secure the dryness of the walls when lathwork is deemed too expensive, consists in leaving a portion of the bricks in the core or middle of the walls, without mortar from the top to the bottom. The interstices thus left, serve, in some measure, the same purpose as the space between the lathwork and the bricks. Perhaps the reference to a figure may make the nature of the plan more easily apprehended. In the nine-inch wall, fig. 8. pl. I. the longitudinal joint *a b*, and the middle third, or from *e* to *f*, of the transverse joint *c d*, would be left without mortar; and the same thing is done to all the other joints or portions of joints similarly situated. By this contrivance, the bond of the wall is greatly weakened; but strength, it will be perceived, is not the object of it; the walls in the inside are drier, they look as well, the house will let for as high a rent as a stronger, and its instability is left for the purchaser, or the next generation, to discover. It has not unfrequently happened, however, that the slightness of modern houses has been quickly proved, by their having tumbled down before they were even finished.

There is one advantage of casing external walls with lath-work, which is independent of damp, and therefore not the object, though the consequence, of that operation. As air is one of the most imperfect conductors of heat known, the column of it included between the plaster or stucco and the bricks, tends to prevent the temperature of apartments from being affected by sudden vicissitudes in the heat of the external atmosphere.—Lathwork casing should be composed of well-seasoned heart laths, as the sap laths will shrink. Reeds are used instead of laths in some parts of the country; but they require a greater quantity of mortar than laths, and produce on the whole little or no saving.

Frost is exceedingly prejudicial to new brick-work, and its effects ought to be guarded against with the utmost care. When it is apprehended, the wall should not be left uncovered at night; a capping of straw, or of weather boarding formed like the roof of a house, to carry off the rain equally on both sides, if any occur, is generally employed; and sometimes, for the more complete security, both the straw and the boarding are employed at the same time, the straw being placed next the wall. In winter, the mortar should be used stiffer than at other seasons, and if a quantity of lime, which is quite fresh, or has been kept in tight casks till it is wanted, were reduced to powder without slaking, and well beat up with it, the setting of it would be very materially hastened. Where strong work is required, it is not expedient, even in winter, to relinquish the practice already recommended, of steeping the bricks in lime-water; and when this is done, the method just mentioned of preparing the mortar, is the more useful. The bricks should not, however, be laid so dripping wet in winter as in warm dry weather. When the practice of steeping the bricks in lime-water is rejected as too troublesome, the sprinkling of each course with common water may be considered the easiest substitute for that operation. This method of strengthening the work, was adopted in the building of the College of Physicians, London, at the judicious suggestion of Dr. Hooke.

If the mortar has been suffered to lie any time, previous to its being used, the labourer should beat it up again to give it tenacity, and to prevent the bricklayer from losing time in working it with his trowel.

In working up the wall, it is by no means advisable to work more than four or five feet in height at a time; for as all walls shrink a little soon after building, if the different parts of the circuit of the walls or carcass be carried up at distant intervals, one part will sink by itself, and will consequently separate from the other part which has become fixed. No portion

of a wall ought to be carried up more than the height of one scaffold above the rest, except in some case of pressing emergency. In carrying up any particular part, each side on the right and left should be sloped off, to receive the bond of the adjoining work.

When the house the bricklayer is employed upon is intended to have other houses parallel with it, half bricks in a straight line with the front, should be left projecting from every alternate course, at the corner or corners to which the addition is intended to be made; or, otherwise, an excavation equal to the breadth of a brick in front, and to the thickness of the wall from front to back, should be left in the alternate courses. In either case, the two fronts will be bonded together, and the gaps, so frequently deforming contiguous houses, when the fronts have been built independently of each other, will be prevented.

Bricks, as a building material, have several advantages over stone; from their porous texture, they unite better with the cement, are much lighter, and the walls built with them are very little subject to damps arising from the condensation of the moisture in the atmosphere. When all materials are ready, a good workman with his labourer will lay a thousand or twelve hundred bricks in one day.

Brickwork is measured by the square foot, reduced to the thickness of one brick and a half; thus a wall two bricks thick, ten feet long, and three feet high, and therefore containing only thirty square feet of surface in front, would be called forty feet reduced. It is valued by the rod of two hundred and seventy-two feet. Facing and gauged arches are measured by the superficial square foot; and cornices by the foot running, or length.

MASONRY.

Masonry is the term used to designate the art of building with stone, as well as the work itself when executed.

Of the Mason's Tools.

The tools required by the mason consist principally of a Level, a Plumb Rule, a Square, a Bevel, a Trowel, a Hod, a pair of Compasses, a Saw, a Mallet, and various sorts of Hammers and Chisels. The whole of these tools, except the four sorts last named, are similar to those bearing the same name among bricklayers, and therefore most of them have already been sufficiently described.

The mason's saw—mallet—chisels.

The masons generally employ labourers to make use of their *saw*, as they can hire them at a cheaper rate than regular artists. The saw is without teeth, and is stretched in a frame, so as nearly to resemble the joiner's frame-saw. It is generally made from four to six feet in length, and for cutting through slabs of uncommon size, it is occasionally made much larger. Its progress through the stone is facilitated by the use of sharp siliceous sand and water. The sand is placed upon an inclined plane, and the water, exuding drop by drop from a small barrel or other convenient vessel, runs over this plane, and carries along with it a portion of sand into the kerf. The workman, in the mean time, slowly drags the saw backwards and forwards horizontally, taking a range of about twelve inches before he makes the return stroke. By this simple process, the hardest calcareous stones are cut into slabs of the required thickness, with very little loss of their substance. But though the practice of sawing stone by hand may be considered easy, it is at the same time slow and expensive.—Mills have therefore been erected in various parts of the kingdom, for sawing and polishing marble, particularly at Ashford in Derbyshire, and at Kendal in Westmoreland. At the latter place, the machinery produces on stone, every moulding which the turner can produce on metal, or the joiner with his plane on wood. The beautiful marbles of the neighbourhood, are wrought at a cheap rate, into various forms, which, from the great expense that would be incurred, would never be attempted by manual labour. It seems to be a desideratum in the management of such machinery, to produce the return of the mouldings. Artists in wood do not require this return, from the facility with which they can make use of mitre-joints; but to the mason, who can rarely adopt joints of this nature, the return of the moulding is mostly an indispensable requisite. In a chimney-piece, or the architrave of a door or window, for example, the return is required on the horizontal piece.

The shape of the mason's *mallet* differs from that of other artists. Its contour is not unlike that of a bell, except that a small portion of the broadest part of it is cylindrical; this part is usually about eight or ten inches in diameter. The handle is just long enough to be firmly grasped in the hand. The chisels are struck with any part of the cylindrical surface.

The *chisels* used by the masons are required to be of various breadths on the cutting edge, but three inches for the broadest, and a quarter of an inch for the narrowest, may be considered the general limits of their sizes in this respect. They are usually made of iron and steel welded together, and the steel extends no farther than they are likely to be ground for use.

When new, they are mostly about eight or nine inches long. The part held in the hand, is generally about five-eighths or three quarters of an inch in diameter, and is forged to an octagonal shape. When the cutting edge is broader than this octagonal portion for the hand, the lower part is first expanded in a dove-tail form, and then the sides for a short distance are parallel to the edge. When the cutting edge is narrower than the octagonal part, the lower end is sloped off in a pyramidal form. The larger sizes of chisels obtain the name of *tools*, the act of using them is called *tooling*, and the stone to which they have been applied is said to be *tooled*. The chisel with the narrowest edge, which is seldom broader, and often not so broad, as a quarter of an inch, is called a *point*. The point is employed to reduce the larger irregularities of a surface, which is afterwards made tolerably regular with the broad chisels or tools. In chipping stone intended to be finished smooth and neat, great care should be taken to avoid splintering the arris, which will almost certainly happen if the edge of the chisel be directed outwards in making the blow. Even for the edge of the chisel to be at right angles to the arris it is applied to form, is not always a safe position; but if directed inwards, so as to form an angle of forty-five degrees with the line of the arris, which it should overhang a little, the chipping may be safely executed. To direct the workman in the use of the chisel, a thin board planed true, is used as a straight-edge, to point out cross-windings and other inequalities of surfaces, the prominent defects of which have previously been removed.

On this occasion, we shall make an observation of which perhaps very few artists are aware. A chisel made entirely of steel, will produce a greater effect with a given impulse than one composed partly of iron and partly of steel, although the steel of the latter forms its edge, and is there equally as good and hard as the steel of the former. But tempered steel is more elastic than iron, and therefore transmits more faithfully the impulse it receives.

In some parts of the country, masons are provided with such hammers as they can use (particularly when they are employed upon the harder kinds of calcareous stones) instead of chisels, as well as for the general purpose of dividing stones. A heavy pointed hammer serves instead of the point, and another which is also heavy, and has an edge like that of a chisel, serves very effectually to produce those narrow marks of furrows left upon hewn stone-work which is not ground on the face.

Of Stones.

All calcareous stones, namely, those that burn to lime, if hard,

of a close texture, and beautiful appearance, from the variegation, or clearness and uniformity of the colours, are called marble. The names of the different kinds of marble are generally derived either from their colour, or the place where they are obtained. The most valuable kind of milk-white marble is obtained in Italy, and is too costly to be often used for any but the smaller ornamental parts of buildings. This, when cut into thin slices, is semi-transparent. Many parts of the united kingdom abound with marble, which is mostly more or less coloured, often close in its texture, and capable of receiving a high polish. Derbyshire and Westmoreland, in England, are the counties which supply the greatest quantity and variety of marbles, some specimens of which are highly esteemed.

When marble that has been faced with a chisel, is intended to be polished, it is ground by rubbing it with rough-grained freestone, assisted by sand and water, until the chisel marks are removed. Finer and fine-grained freestone, with water, but no sand, is then used, till the surface becomes very smooth. If the finer grit-stones be found too slow in their operation, a little fine flour of emery is used. The last and highest lustre is given with oxide of tin, well known under the name of putty. When the surface of the marble to be polished has been cut with a saw, the very rough freestone and sand are not necessary. In other respects it must be finished by the same process.

Limestone is a coarse kind of marble, and is cut and polished in a similar manner. In many districts, it forms immense strata. From its great hardness, it is only hammer-dressed when used for the fronts of buildings; but when this is done in the best manner, the effect is very fine.

The stone most commonly used in London, is Portland stone, which is brought from the island of Portland in Dorsetshire. It is of a dull whitish colour, though the buildings constructed with it have a handsome appearance. When recently dug, it is soft, and easy to work, but acquires hardness with age. Although it contains silex, the hardness it acquires is not so great that it will strike fire with steel. Under great pressure, Portland stone is apt to splinter at the joints.

Purbeck stone is brought from the island of Purbeck, also in Dorsetshire; it is mostly employed in rough work, such as steps, paving, &c.

Freestone is a general name for stones of very different qualities as to their value in building. It consists of clay and silex, sometimes the silex amounts to nearly one-half its weight, but generally it is considerably less, and the hardness of the stone varies with the proportions of its component parts.

is often called grit or sand stone. It is a very plentiful stone; the strata of entire districts, under a slight covering of soil, appearing, in various instances, to be composed of it. The particles of some kinds of it have so little cohesion, that small bits may be granulated between the fingers; this is the sort commonly used for filtering-stones. All kinds of it are softer when taken out of the quarry, than they afterwards become when dry, or after long exposure to the atmosphere. Freestone is generally about two and a half times the weight of water. That from Hollington, near Utoxeter, is of a whitish or yellowish gray; that from Knipersly, in Staffordshire, is of a bluish gray, and so infusible as to be used as a fire stone. The colour of freestone is often a dull red, but sometimes so nearly white, that buildings constructed with it look as well as those of Portland stone. Different parcels of freestone, taken from the same quarry, frequently exhibit a considerable diversity of colour; a circumstance which gives a motley appearance to buildings in other respects perhaps faultless. When the stone has been recently dug, and is damp, these differences are often not perceptible. If, therefore, uniformity of appearance be desired, the stones should be faced, dried, and sorted before they are used. Freestone is incapable of receiving a polish, and therefore, when it has been cut with a saw, it is rarely submitted to any subsequent operation to produce greater smoothness; but when it has been reduced with the chisel, it is made smooth with another piece of stone of the same kind, along with sand and water. When the freestone has a laminated texture, it is called flag-stone, and is divided into thin pieces for the purpose of covering houses, and for flooring.

The position which stones have had in the quarry, is not a matter of indifference to the attentive mason. Stones intended to sustain great vertical pressure, as pillars, should stand in a building as they stood in the quarry from which they were taken; for pillars, the axis of which were horizontal in the quarry, when placed perpendicularly, are apt to split under a great strain. Perhaps all stones, however solid they may appear, possess more or less of a laminated texture,—a property doubtless occasioned by separate depositions, or crystallizations of their peculiar matter. What kind of a pillar any stone well known to be laminated, would produce, in different positions, it is not difficult to conjecture. If, for example, a block of flag-stone were converted into a pillar, so as to leave each lamina or flag of which it is composed posited horizontally, it would sustain any weight not capable of crushing it to atoms; but if the lamina were placed in an inclined position, so as to form an acute angle with the axis, an inconsiderable pressure

would occasion them, where the cohesion was slightest, to slide over each other; lastly, if the lamina were placed parallel to the axis, the pillar, under sufficient pressure, would divide vertically into several parts, and though rather stronger than in the last instance, would still be comparatively weak. An attention therefore to the position of stones, and to veins or other signs which may indicate the existence of lamina, well deserves the mason's regard.

Of Cements.

The cement used by the mason, for the ordinary purposes of walling, is mortar, differing not from that used by the bricklayer; and as we have already treated of this subject rather at length, a few remarks in this place will suffice. For the joints of hewn stone, the mortar should be much finer than the bricklayer requires; and sometimes a mixture of oil-putty, or very thick white-lead paint, is used as the cement. These compositions will last longer than almost any stones, and will remain prominent when the face of the softer kinds of stone has been corroded by age.

The cement used in setting column stones, is mostly oil-putty, or white lead mixed with chalk-putty, or fine mortar. Sometimes columns are set upon milled lead; in this case, the lead should not be quite equal to the column in diameter, but so as to leave a narrow ring externally, which must be filled with oil-putty.

In situations not exposed to damp, plaster of Paris is employed as a bedding for stones or marble. When a mantle-piece is composed of valuable marble, the various pieces are commonly very thin. In this case, a considerable thickness of plaster of Paris is laid on the back, and a slate or some ordinary stone bedded in it, to give greater strength. Good plaster of Paris is scarcely to be met with, nor are the causes of its imperfections generally understood by workmen. We shall therefore point them out, and give directions for preparing it, of a uniform and excellent quality, when we treat of casting in plaster.

The Greeks and Romans constructed their works of wrought stone without cement; but as they used a profusion of cramps and bands of iron and bronze, and the beds of the enormous stones they used were finished with almost mathematical precision, their edifices were substantial and durable in the highest degree. Metallic bands and cramps are still used in aquatic works, as well as for lofty steeples, and other slender buildings much exposed to the action of the winds, also to connect the different stones composing mantle-pieces, &c. with the wall.

Of Stone Walls.

The propriety of erecting suspended or inverted arches, according to circumstances, and other general directions already given respecting foundations, being as applicable to stone walls as to those of brick, need not be adverted to again. The explanation of a few technical terms will therefore be our first object.

Stones which run through the thickness of a wall, in order to bind it, are called *bond stones;* in some parts of the country they obtain the name of *through stones.*

When the side or sides of a wall lean back, so that the plumb would fall within the base of the wall, the inclination is called *battering;* it is generally made about one inch in a foot.

The large stones at the base of a foundation, which project beyond the vertical surface or front of the superincumbent wall, are called *footings.*

The parts of a wall between apertures, or between an aperture and the corner, are called *piers.*

The *beds* of a stone are its upper and under surface, which are generally in a horizontal position within the wall.

Walls built with unhewn stone, with or without mortar, are called *rubble walls.* Rubble walls are of two kinds, the coursed and the uncoursed. In the coursed, the stones are hammer-dressed or axed, and adjusted by a sizing rule, so that each row of stones forms a horizontal surface. In the uncoursed, the stones are used in a rough state, nearly as they come out of the quarry.

Walls which are faced with squared stones, hewn or rubbed, and backed with rubble, stone, or brick, are called *ashlar.*

Wall-plates, are horizontal pieces of timber, commonly laid even with the interior of walls, for the ends of the joists and other timbers to rest upon.

The footings of walls ought to consist of the largest stones which can be conveniently procured. It is better to have them of a rectangular form than any other, and if not square, their largest surfaces should be laid horizontally. With this shape and disposition, they will make the greatest resistance to sinking. If the stones, intended to be employed as footings, deviate materially from a rectangular figure, when received from the quarry, they ought to be hammer-dressed; as, if they taper downwards, or rest upon angular ridges, they will be apt to give way under the weight of the superstructure. When the footings can be obtained the full breadth of the wall in one piece, they are to be preferred; but when a sufficient number of stones of this description cannot be obtained, then every

alternate stone in the course may be the whole breadth, with two stones next to it, disposed like two stretchers in a nine-inch wall of Flemish brick-work. When the largest stones which can be conveniently obtained, are insufficient even for the latter arrangement, the most suitable which can be procured, must be disposed so as to break in the best manner circumstances will admit, the vertical joints in the same course, as well as those of the different courses with respect to each other. Each course, also, should be well bedded in mortar.

When bond timber will be required, the uncoursed rubble is an inconvenient mode of building, as the heights on which they are disposed must be levelled. The best kind, or coursed rubble, admits of bond timbers without difficulty, for though the different courses are not of the same height, the surface of each of them is level; but as the walls in which bond timbers are introduced, are apt to warp or even fall in case of fire, the use of them should be avoided in strong well-built walls.

The stones of an ashlar front should have their upper and under surface correctly parallel with each other, and correctly at right angles to the face. If these surfaces be carelessly left concave, they will be apt to splinter near the edge under great pressure. On the right and left they should taper inwards, but the taper should not be continued quite to the face, though it may reach the face within an inch or two. The ashlar stones having the form of a truncated wedge, they will, in each course, present a series of angular indentations within the wall, like the spaces between the teeth of a saw. The stones are so selected and disposed that the vertical or upright joints, and consequently the angular spaces, of one course fall on the middle of the stones below. By this means the ashlar face is bonded to the rubble, brick, or rough stone of the back, and the strength of the wall much greater than if each stone was of an equal rectangular figure. Strength is also to be promoted by adopting a plan not commonly regarded, that of sorting the stones, so that in each alternate course they will extend farther into the wall than those of the course immediately above and below. In ashlar work, the bond stones, which ought frequently to be introduced, cannot like the other stones have a wedge-like form; they must be rectangular; and they produce the best effect, when so disposed in each course that they will be opposite the middle of the space between the two bond stones in the course immediately above and beneath them.

Of Stone Columns.

When large stone columns are made in one piece, their effect, from that circumstance alone, is very striking; but as this advantage is not always obtainable, the next object is to make the joints as few and as minute as possible, as well as to be very attentive in selecting the different stones to be combined, that the joints may not be descried at a distance, by the commencement of a different colour. From what has been said in the section on the different kinds of stone, it will be understood, that none but horizontal joints can be allowed in any shaft; all others being inconsistent with the laws of strength.

The stones proper for an intended column being procured, and the order in which they are to succeed each other being determined, the next consideration will be to ascertain the exact diameter proper for each end of every one of them. For this purpose, draw an elevation of the proposed column to the full size, divide it by lines parallel to the base, into as many heights as the column is intended to contain stones, taking care that none of the heights exceed the length that the stones will produce. The working of the stones to the diameters thus obtained then becomes easy. The ends of each stone must first be wrought so as to form exactly true and parallel planes. The two beds of a stone being thus formed, find their centres, and describe a circle on each of them. Divide these circles into the same number of equal parts, which may, for example, amount to six or eight. Draw lines across each end of the stone, so that they will pass through the centre, and through the opposite divisions of the same end. The extremities of these lines are to regulate the progress of the chisel along the surface of the stone, and therefore when those of one end have been drawn, those of the other must be made in the same plane, or opposite to them respectively. The cylindrical part of the stones must be wrought with the assistance of a straight-edge; but for the swell of the column, a diminishing rule, that is, one made concave to the line of the column, must be employed. This diminishing rule will serve to plumb the stones in setting them. If it be made the whole length of the column, the heights into which the elevation of the column is divided, should be marked upon it, so that it may be applied to give each stone its proper curvature. But as the use of a long diminishing rule, when the stones are in many and short lengths, would be inconvenient, rules corresponding in length to that of the different heights, may be employed with advantage.

To draw the curve of a shaft.

Of the different methods which may be practised, to obtain the curvature of the rule to be used in the diminution of the shaft of a column, the following may be considered the easiest and best adapted for general use: Let A B, fig. 12, pl. I. represent the height of the column, *e f* the semi-diameter of the lower part, and *g h* the semi-diameter of the upper part, according to the customary proportion of the diminution. As the lower one-third of the column must be cylindrical, draw a line from *e* to *i*, parallel to A B. What we now want is, to obtain a curved line from *i*, which will fall into *g* without making the diameter of the upper two-thirds of the column in any point greater than that of the lower or cylindrical third. With the radius *i k*, draw the quarter of a circle C. Draw a line from the narrowest part of the column, that is from *g*, parallel to the axis or middle line A B, till it cuts the quadrant of a circle C. Divide the arc contained between *i* and the point where *g* cuts C, into four equal parts, as *l, m, n, o*, and divide the height A *k* into the same number of divisions as this arc, as 1, 2, 3. From the point *m*, draw a line parallel to the axis, which will cut the transverse line 3 at *v;* from *n* draw another line parallel to the axis, which will cut the transverse line 2 in *w;* in the same manner draw a line from *o* to the transverse line 1, which it will cut in *x*. Now the curved line of the column, between *i* and *g*, must pass through the points *x, w, v;* therefore at or near all the points from *i* to *g* inclusive, drive in two pins or nails, in such a manner that the direction in which each pair of nails stand shall be the same as the transverse lines of the column. Between each pair of nails, also, there must be just sufficient space left to admit a thin slip of wood, like a lath, or some other equally flexible substance, and care must be taken to fix the nails in such a position, that when this slip of wood is placed between them, either its inner or its outer perpendicular surface shall exactly coincide with the several points of diminution *i, x, w, v, g*. This being done, it is easy, with a pencil or any marking instrument suited to the surface worked upon, to draw a line along the slip of wood, which line will be the curve of the shaft. The piece intended to be used as a diminishing rule may have the curve made on it, or transferred to it, as may be deemed most convenient. It will also be understood, that the number of the parts into which the arc *l i*, and the height A *k* are divided, and which determine the number of diminishing points obtained, may be varied at pleasure. In no case, however, can it be considered advisable to make these divisions fewer than four, though for lofty columns they may be made two or three times that number, as they constitute so many checks upon the irregular or

imperfect flexibility of the lath or spring rule. As so much of the beauty of a shaft depends upon the easy and imperceptible transition from the cylindrical to the tapering part, it may be advantageous to divide the arc from *i* to *o* into two parts, and the division *k* 1, of the shaft, also into two parts; a diminishing point will then be obtained between *i* and *x*, which will be of use to lessen the possibility of imperfection.

Another mode, which we shall recite, of diminishing a shaft, is not essentially different from the preceding: divide the shaft from D to E, fig. 17, into four parts, as 1, 2, 3; divide the space EF, which is the difference between the superior semi-diameter E *r*, and the inferior or lower diameter D *q*, into the like number of parts, viz. four. Draw lines from each division on EF tending to the point D. The first line next to F will reach to D, the point from which the diminution commences, in a direction parallel to the axis; the next line, reckoning from the same side, will give the point *a;* the third line the point *b;* and the fourth line the point *c;* a line from the point E, which is the limit of the diminution, need not be drawn. The points E, *c*, *b*, *a*, D, constitute the places where the nails must be driven in, to direct the path of the lath as in the last example. Some artists prefer this mode of diminution. Here, also, as before, the number of the divisions is optional, but a greater error may be committed by making them too few than too numerous.

To draw the flutes and fillets on the shaft of a column, the following will be found an easy and effectual method: let A, fig. 10. pl. II. be the shaft; make a hole exactly in the centre of both ends, and into each hole drive a piece of wood, so as to be quite tight, and to project five or six inches. The projecting parts, *b b*, of the pieces of wood, must be well rounded off, and made exactly in the middle of the ends. Being provided with a diminishing rule, made as above-mentioned to the curve of the shaft, it may here be used as the ruler, by fixing it in a groove in two pieces of wood, *c c*, so as to revolve with them upon the pins *b b*. The edge of the rule must be brought very near the shaft, and one side of it must tend exactly to the centre, which is done by giving that direction to one side of the grooves in *c c*, as shewn by the dotted lines *a a*. As the diminishing rule *d*, is commonly made rather slender, and therefore will be apt to bend with the force employed to draw the lines, it will be proper to fix a piece of wood, of sufficient thickness to keep it straight, on the back, or that side of it which does not tend to the centre. As in marking a long column, there may be some difficulty in keeping the rule steady, while the lines are drawn, the strong piece

of wood thus attached to the back of the diminishing rule, may have one, two, or more screws, according to its length, passing through it, as *f f*, and pressing against the shaft, by which means the rule will be staid at any part of a revolution, much more effectually than with the assistance of several men. The screws ought to be of wood, or, if iron, their extremities should be prevented from injuring the stone, by the interposition of a flat piece of metal, or some other suitable substance. These arrangements being made, the lines desired may be drawn with any sharply-pointed steel instrument kept close to the rule, with the greatest ease and precision, from divisions previously marked at one end. To obtain these divisions, suppose it were desired to flute the Ionic, the Corinthian, or Composite columns, the circumference at one end will be divided into six equal parts, by taking half the diameter at that end, and applying it round the said circumference; and if each of these divisions be divided into four, the whole circumference will be divided into twenty-four. In order to make the proportion of a flute to a fillet as *one* to *three*, divide any one of these last divisions, or twenty-fourth part of the circumference, into four equal parts, and one of these parts will be the breadth of a fillet; which being set off from the same side of each division, the whole shaft will be properly divided for flutes and fillets, and consequently prepared for the use of the rule.

To draw the flutes and fillets on a diminished pilaster, make a line down the middle of the face of it, from top to bottom; divide this longitudinal line into any convenient number of equal parts, and through the points of division draw transverse lines crossing the breadth of the pilaster; set off the flutes and fillets on each transverse line; fix pins or nails at each corresponding point of the transverse line, and draw the lines with the help of a pliable slip of wood, as in obtaining the diminution of a shaft.

Stone Bridges.

Here it will be proper, in the first place, to give an explanation of the principal terms used in speaking of bridges.

The *abutments* of a bridge are the walls adjoining to the land, each of them supporting the end of an extreme arch.—The walls supporting the ends of the arches between the abutments, are called *piers*.

The *imposts* are the highest course of the stones of piers, from which an arch immediately springs, and which project a little from the piers.

Batterdeau, or *Coffer-dam*, a case of piling, to divert the stream of a river while the piers are building.

The *span* of an arch is its greatest horizontal width.

Caissons are large hollow vessels, framed of strong timbers, and made water tight, which being launched and floated to a proper position in the river, where the bed has been previously excavated and levelled, are there sunk. The piers of the bridge are built within them, and when carried up above or nearly to the level of the water, the sides of the caisson are detached from the bottom, and removed; the bottom is left remaining, and serves for a foundation to the pier.

Drift, push, shoot, thrust, terms used indiscriminately, to express the horizontal force of an arch, by which it endeavours to spread itself out and overset the piers and abutments.

The *extrados of an arch* is the outside or convex curve on the top of the arch stones: hence the *extrados of a bridge* is the curve of the road-way. Extrados is the term opposed to *intrados,* which signifies the concave side of an arch.

Those stones, one side of which is in front, and another side forms part of the intrados of an arch, are called *voussoirs* or *arch-stones;* the middle voussoir, at the summit of the arch, which is put in last, for wedging and closing the whole, is also, and indeed most commonly, called the *key-stone.*

Parapets are the low walls erected on the sides of the extrados or road-way of a bridge, for the safeguard of passengers.

These explanations being premised, we may proceed with the subject. Palladio observes, that bridges ought to have the same qualifications which are deemed necessary in all buildings of consequence, namely, that they should be convenient, beautiful, and lasting. To make a bridge lasting, the goodness of its foundation is one of the most important things to be attended to; to make it convenient, an easy ascent, and a width suited to its situation, are absolutely necessary; and to make it beautiful, its workmanship must be good, and its several parts well designed and proportioned.

Bridges ought always to be constructed at right angles to the current. The piers ought to be so proportioned, as to enable them to withstand the thrust of the adjoining arches, though the rest were thrown down; yet to fall short of the size required for this purpose, would hardly be a greater fault than materially to exceed it; for when the piers are unnecessarily large, the current being contracted, increases its velocity, and is apt to undermine the foundation.

A judicious regard to local circumstances, is always of great importance to the durability of a bridge. Over rivers which are subject to great inundations, arches that will be dry at ordinary seasons will often be necessary; and when a choice with respect to the situation can be made, a wide part of the

stream should be preferred to the narrow part, because the water at the narrow part has not only a greater velocity than at the other, but that velocity would be increased by the space which the piers would occupy. Another point to be duly regarded in selecting the site of a bridge, is the solidity or otherwise of the ground in different parts of the river, for the foundations of piers and abutments. An immense expense in piling, and other artificial means of improving inadequate ground, may often be saved by proper attention in this respect.

The arches in a bridge ought to be an odd number, that one of them may stand in the middle, where the velocity of the stream is greatest. The middle arch is also to be made the largest. As the expense of piers is very considerable, besides the perpetual inconvenience of them in navigable rivers, bridges should always be constructed with the fewest arches possible.

With regard to the most suitable curve for the arches of a bridge, the subject has been much controverted. Not only architects, but mathematicians have, on this point, differed widely from each other. This diversity of judgment seems to have been perpetuated by the fact, that bridges of acknowledged, and to all appearance of equal excellence, have been constructed with semi-circular, semi-elliptical, and curves of various other denominations, and consequently possessing very different properties. Some have contended that semi-circular arches ought in most cases to be preferred, because they press more perpendicularly upon the piers than smaller portions of circles, and in proportion to their number will diminish the pressure on the abutments. Others have preferred the elliptical curve, where the arches were to be large and but few in number, because the extensive radius of the semi-circular arch would occasion the central part of the extrados or road-way to be very inconveniently elevated. This objection to the semi-circular form is obviated by adopting the elliptical one, and Muller asserts that the elliptical arch does not press against the piers with a greater force than a circular one; and being lighter, from requiring a smaller quantity of materials, will consequently be more lasting.

As the strength of a bridge depends so much on mathematical principles, it seems natural to look for, and to regard with deference, the opinions of the most eminent mathematicians. If mere theorists differ from each other, those who enjoy alike the light of theoretical and practical knowledge, may discover the sources of the errors which have occasioned contradictory deductions. It was the opinion of the celebrated Dr. Hutton,

late professor of the mathematics to the royal military academy, Woolwich, that the mechanical arch of equilibration is the only perfect one adapted to the principles of bridges. This arch, it is asserted, being in exact equilibrium in all its parts, can have no tendency to break in one part more than another, and must therefore be the safest and strongest. A table for constructing the arch of equilibration, is given in the Doctor's Mathematical and Philosophical Dictionary, under the article Bridge. To explain the nature of the equilibrated arch, we shall advert, in the first place, to the construction of the catenarian curve. If a perfectly flexible rope, of equal thickness and density in every part, were fastened by its ends to hooks, or some other supports, at any distance insufficient to draw it tight, the position which it would assume is called the catenarian curve. This is a curve which has had many advocates, among whom is found the celebrated Emerson, who considered it of all curves the best adapted to bridge building. The fact is, that if the arch of a bridge were, like the rope, of uniform thickness (which for the present we will suppose to imply uniform density) in every part, the catenarian curve would be the most proper for it, because that curve, under such circumstances, is a true arch of equilibration. Hence, as the uniform thickness of an arch can rarely be made compatible with other objects in constructing a bridge, the catenarian curve can as rarely be the proper arch to use. Every particular form of the extrados of an arch, requires, according to the principles of equilibration, a difference in the form of the intrados. To render this more clear, we will return to the consideration of the rope, suspended as above stated. Supposing it to hang along a wall, the curve it exhibits may be traced. When this has been done, let the substance of the rope, on the convex side, be increased in some parts, for example, at the haunches; it will then no longer describe a catenary, and it would be found that every difference in the additions made to it will produce a difference in its curvature. If the experiment could be made with materials really possessing perfect flexibility, these differences would be very perceptible, and if the points of suspension were at a distance from each other just equal to the diameter of a circle which the rope would half encompass, it would be found that the rope would require the additions made to it to be as represented by No. 2, fig. 11. pl. II. before the concave side of it would describe a semi-circle. But when these additions were made, the contour of the figure, if introverted, as shewn by No. 1, would represent the section of an equilibrated arch, the intrados of which should be semi-circular. As

an extrados or terminating line of wall running up at both ends in this manner, is far remote from any form that is admissible in practice, semi-circular arches are never balanced or equilibrated; and the advocates of the equilibrating system assert, that though such arches have stood for centuries, this event has only happened in consequence of the cement and friction which have prevented the stones from being pushed out of their places. Hence, they add, that if the materials were only placed in contact, without cohesion or friction, they would not stand when the road-way was straight, or a convex curve throughout the length of the arch, or in any other way different from the figure above referred to.

These observations will, we hope, communicate to the reader, an idea of the nature of equilibrated arches. The subject is interesting and important, and to dismiss it without some explanation of this kind, would be denying it the notice to which it is fairly entitled. Here, however, it may be observed, that the subtle refinements of theory, whatever may be their general utility, are not always found to be directly applicable to practice; and we may therefore sometimes act in opposition to them, not only with safety, but with advantage. Bridges, which have not been equilibrated, have, as before stated, endured for ages, and appear likely to endure till the materials of which they are composed crumble away. Hence we are afforded a reasonable encouragement to construct again such arches as they are composed of, whenever their form suits us in other respects. Though the mathematical reasoning on arches of equilibration be just, yet it applies with strict propriety only to homogeneous materials, and to structures acted upon by no power but that of gravitation. If the form it prescribes were attended to, it would cease to be an arch of equilibration, under the pressure of a waggon or any other load; and without the friendly aid of cement and friction, would no more be able to stand than any other kind of an arch. In the practical operations, also, of constructing a bridge, the proper configuration of the stones for many kinds of curves, either cannot be determined by any unexceptionable rule, or if determinable, is apt to be mistaken, and subject to considerable difficulties of execution. The aggregate of small deficiencies originating in this way, is, in extensive structures, incalculably subversive of strength. Semi-circular arches, or those of any less portion of a circle, having all their stones of the same figure, and which therefore it is easy to form with correctness, and impossible to misarrange in the work, are, there can hardly be a doubt, more uniformly built strong, than any other

kind of arches. Next to circular curves, elliptical ones admit the stones of which they must be composed to be formed in the most certain and satisfactory manner, and though it may be much more difficult in them, than in circular arches, to make the surfaces intended to be in contact, press against each other simultaneously and uniformly in every part, under any constant or occasional weight, yet with care it may be done, or at least the imperfection may be so small as to produce little ultimate disadvantage. For other curves, it appears difficult to contrive an easy and unexceptionable mode of forming the stones, or to determine from what point or points, their joints should appear to radiate; besides the constant risk, from their varied shapes, of putting them in wrong places. But as semi-elliptical arches approximate very nearly to the form of equilibrated arches, as their contour is not only graceful, but, in navigable rivers especially, very convenient, from the elevation of their haunches, as they can be made also to so great a variety of heights with the same span, and combine with these properties the greatest facility of execution, next to the circular form, the opinion of architects generally is, for extensive structures, decidedly in their favour. In small bridges, a semi-circular arch may be adopted with propriety, where the extra quantity of materials required by that form is no object, and when a strong arch of the easiest execution is desired. When a semi-circular arch would be too elevated for the situation, a segment of a circle not exceeding sixty degrees, may be employed.—All arches, less than a semi-circle, are called *scheme-arches*.

The dimensions of the piers of bridges are commonly determined by those of the arch. Their breadth should not exceed a fourth, nor be less than one-sixth of its span. To break the force of the current, they have mostly angular ends so as to present an edge in front; though sometimes their ends are semicircular, in order that such bodies as are impetuously brought down the river, when they strike against them, may be deflected towards the middle of the arch. To prevent the stability of the piers from being endangered, by the washing away of their foundations, occasioned by an increased velocity of the current, the bed of a river must be sunk or hollowed in proportion to the room taken up by the piers, in order that the water may gain in depth what it looses in breadth; or the current may be broken, by stopping the bottom with rows of planks, stakes, or piles. The celebrated Palladio gives the following proportions of a bridge designed by him: the river was one hundred and eighty feet wide; making three arches in the bridge, he gave sixty feet to the centre arch, and to the other two forty-eight feet

each. The piers were twelve feet thick, or one-fifth part of the span of the middle arch, and a fourth part of that of the smaller ones. The arches were a little less than a semi-circle, and their keystone one-seventeenth part of the span of the middle arch, and one-fourteenth part of the other two. In an arch of twenty-four feet, Palladio makes the length of the keystone about sixteen inches, which is deemed a very eligible size.

Autumn is in general the most favourable time to lay the foundations of a bridge, as it is commonly the driest season of the year, and the consequent lowness of the waters is favourable to the work. The simplest mode of overcoming the inconvenience of the water, in laying the foundations of piers, consists in turning the river out of its course, above the place designed for the bridge, into a new channel cut for it near where it makes an elbow or turn. As this plan is, however, seldom expedient, and often not practicable at a reasonable expense, the use of the coffer-dam, or enclosure to keep off the water, is much more common. By the coffer-dam, a part only at a time of the bed of the river is enclosed from the water, which flows in a free current along the unenclosed parts of its bed. An account of the method employed by the ingenious Robert Semple in laying the foundations of Essex-bridge, in Dublin, will illustrate this subject. Round the place where the intended pier was to be built, two rows of strong piles were driven, about thirty inches from each other, and which were left at low-water-mark. These piles were lined with planks, between which was rammed a quantity of clay, and thereby the wall of the coffer-dam was formed. Within this wall were driven a row of piles, dove-tailed at their edges, so as to receive each other, and which formed the extremities of the plan of the piers at the level of the bed of the river. After having dug to a fine stratum of sand, about four feet lower, within these a great number of other piles were driven as deep as they could possibly be made to penetrate. The intervals of these piles were filled up, and in order to produce a solid foundation, the first course was laid with mortar made of roach-lime and sharp gravel, and on this large flat stones were rammed to about a foot in thickness. On this first course was laid a thick coat of dry lime and gravel of the same quality, on which were again laid stones and the mortar as at first; and so on alternately, until the pier arrived at a level with the piles. Three beams, stretching the whole length of the pier, from sterling to sterling, were fastened down to the ends of these piles, and their intervals filled up with masonry. On this platform, which was four feet six inches under low-water-mark, was laid the first course of stones for the pier, cramped together,

and jointed with terras mortar as usual; courses of stones were laid in this manner, until the piers were on a level with the water at ebb-tide.

The caisson is a contrivance of still more extended utility than the coffer-dam, from being better suited to very deep and rapid streams. The most considerable work where caissons have been employed, was in the building of Westminster-bridge, of which, therefore, a particular account may be interesting. Each of the caissons contained one hundred and fifty loads of fir timber, and was of greater tonnage than a frigate of forty guns; their size was nearly eighty feet from point to point, and thirty feet in breadth; the sides, which were ten feet in height, were formed of timbers laid horizontally over one another, pinned with oak trunnels, and framed together at all the corners, except the salient angles, where they were secured by proper iron-work, which being unscrewed, would permit the sides of the caisson, had it been found necessary, to divide into two parts. These sides were planked across the timbers, inside and outside, with three-inch planks in a vertical position. The thickness of the sides was eighteen inches at the bottom, and fifteen inches at the top; and in order to strengthen them more, every angle, except the two points, had three oaken knee timbers properly bolted and secured. These sides, when finished, were fastened to the bottom or grating, by twenty-eight pieces of timber on the outside, and eighteen within, called straps, about eight inches broad and three inches thick, reaching and lapping over the tops of the sides. The lower part of these straps were dove-tailed to the outer curb of the grating, and kept in their places by iron wedges. The purpose to be answered by these straps and wedges was, that when the pier was built up sufficiently high above low-water-mark, to render the caisson no longer necessary for the masons to work in, the wedges being drawn up, gave liberty to clear the straps from the mortises, in consequence of which the sides rose by their own buoyancy, leaving the grating under the foundation of the pier. The pressure of the water upon the sides of the caisson, was resisted by means of a ground timber or ribbon, fourteen inches wide and seven inches thick, pinned upon the upper row of timbers of the grating; and the top of the sides was secured by a sufficient number of beams laid across, which also served to support a floor on which the labourers stood to hoist the stones out of the lighters, and to lower them into the caisson.

The caisson was provided with a sluice to admit the water. The method of working was as follows: a pit being dug and levelled in the proper situation for the pier, of the same shape

as the caisson, and about five feet wider all round, the caisson was brought to its position, a few of the lower courses of the pier were built in it, and it was sunk once or twice to prove the level of the foundation; then, being finally fixed, the masons worked in the usual method of tide-work. About two hours before low water, the sluice of the caisson, kept open till then, lest the water, flowing to the height of many more feet on the outside than the inside, should float the caisson and all the stone-work out of its true place, was shut down, and the water pumped low enough, without waiting for the lowest ebb of the tide, for the masons to set and cramp the stone-work of the succeeding courses. Then, when the tide had risen to a considerable height, the sluice was opened again, and the water admitted; and as the caisson was purposely built but ten feet high to save useless expense, the high tides flowed some feet above the sides, but without any damage or inconvenience to the works. In this manner the work proceeded, till the pier rose to the surface of the caisson, when the sides were floated away, to serve the same purpose at another pier.

To change altogether, for a time, the course of a river, by providing it with a new channel; or to divert a part of the current at once by the erection of a coffer-dam, may be classed among the simple and obvious expedients, to obtain the means of laying the foundations of a bridge, which would suggest themselves in the infancy of aquatic architecture. Improvement seems to have gone no further for a long time. In early periods, if the first means that suggest themselves to accomplish the end in view, possess the two grand requisites of possibility and efficiency, the march of invention is impeded by a willing prodigality of labour. The caisson, an invention of greater refinement, and bolder aspect, probably originated in a much later period; but when the success which attended the use of it once became familiar to architects, the transition seems natural and easy, from a caisson of wood, which is floated away when no longer wanted, to a caisson of stone, which should permanently remain the external part of the pier. It would soon appear to the mind of him who was first struck with this happy idea, that by the common well-known means, the stones might be cemented so perfectly as to be impervious to water; that they might be cramped so firmly together, likewise, that no force to which they need be exposed would injure the work; and that as the weight of the heaviest stones employed in building is only about two and a half times greater than that of water, the proportion which must subsist between the solid and the hollow part of any mass of masonry intended to float, could not only always be determined with facility,

but was so small as not to occasion a fear of success. Indeed, so great appears to be the practicability of the plan, that the praise of ingenuity exclusively belongs, not to him who shall carry it into execution, but to him by whom it was first suggested. We shall proceed concisely to notice a few particulars respecting it. General Bentham took out a patent, dated April 2, 1811, for a new and economical method of laying the foundations for bridges, wharfs, &c. He proposes the construction of hollow masses of masonry, brickwork, &c. which he would afterwards float to and sink at the place desired. He observes, that these masses, if filled with casks, might be floated without having themselves any bottom; and directs a calculation to be made of the weight which any of them will have to bear when employed as piers, or for any other purpose, so that vessels properly loaded may be grounded upon them, and by that means sink them, when the tide retires, as low as they would otherwise have been ultimately sunk by the weight they are to sustain, and thus prevent their sinking after the structure is finished. J. I. Hawkins, in a letter to the Editors of the Repertory of Arts, &c. states, that, several years previous to the date of the above specification, he had mentioned the leading feature of the General's plan, and also of that with respect to the suspension of centering, proposed by Telford, in his report to the House of Commons, for throwing a bridge over the straits of Menai, to several of his friends, who highly approved of them. He attributes not disingenuity to these gentlemen, in borrowing his plans, being aware of the similarity of ideas which may occur to different persons, independent of each other, when engaged with the same subject; but lays claim to priority of invention, and developes to the public the particulars of a plan which he had long before circulated among his friends. He would build his piers on shore, in some situation where they might be launched like a ship; he would cramp the outside stones strongly with iron, and would make the walls of such a thickness that they might float in water. He would have a valve in the wall, to admit water whenever it might be proper to sink the pier, and a pipe fixed through the top, communicating with the lower part of the inside, on which pipe a pump must be fixed, for drawing the water out, should that measure be necessary.

To form a good foundation, a space in the bed of the river, rather larger than the base of the pier, must be excavated and levelled by the means used in taking up ballast, and the spot must be piled, if necessary, as on other occasions of the kind. He details the means of making a platform over the place intended for erecting the pier, which, when sunk, must have

bricks or stones let down into it equal at least in weight to the water required to sink it. The water must then be pumped out, when the workmen may descend, to lay the stones or bricks in mortar, and fill up the whole interior; thus he obtains a solid pier.

In situations where, from the state of navigation, or any other cause, it may be inconvenient to erect centering in the customary way, he would not hesitate to adopt suspending chains. However bold the idea may appear, it will not be deemed impracticable, when it is considered that the weight of an arch of any given dimensions is easily calculated, and the suspending power of iron is known; consequently no arch can be so heavy, but that a sufficient number of chains may be provided to bear more than the weight. The chains may be advantageously composed of long bars of iron, merely turned up at the ends, so that when done with, they may have these ends cut off, and be sold as bar iron again.

That the piers of bridges may be built hollow, and rendered perfectly manageable in or under water, at a considerable depth, is put beyond a doubt by an experiment which J. I. Hawkins conducted for the Thames Archway Company. Two hollow cylinders of brickwork, upwards of eleven feet diameter, and twenty-five long each, were sunk through thirty feet of water in the river Thames, and bedded precisely at the spot proposed. These cylinders were built in a barge, in October and November, 1810, and launched into the water, where they remained floating all winter, and were sunk in the river in the spring of 1811. They were under such perfect command, that from a stage erected on the bed of the river, and supplied with suitable windlasses, pulleys, ropes, &c. they were lowered, raised, or moved, in any lateral direction without difficulty. These experiments left not a doubt, that masses of masonry, of large dimensions, might be fixed through the water, in the bottom of a river or harbour, to the depth, if requisite, of one hundred or more feet. They were instituted for the purpose of ascertaining the practicability of forming a tunnel under the Thames, upon a cheaper and more certain plan than undermining it, as was first projected. The result proves, that by this method, communications may cheaply and to a certainty be formed between the opposite shores of rivers, in almost all situations where the navigation, or any other circumstance, renders bridges inadmissible.

The inventions recorded in the preceding details, promise the dawn of a new era in the science of aquatic architecture. They extend incommensurably the limits of our views, and will lead to undertakings of the boldest and most novel

character. Telford, in his report to the House of Commons, on throwing an iron bridge of one arch over the straits of Menai, to connect the Isle of Anglesea with the county of Carnarvon, proposes to suspend the centering, although the span of the required arch will be six hundred feet.

The common breadth of bridges is about thirty feet; but when they form the avenues to large towns, the carriage road is nearly this breadth, and they have besides a raised foot-path from six to nine feet broad on each side. The breadth of Westminster bridge over the Thames is forty-four feet, and the breadth of Blackfriars' bridge, over the same river, forty-two feet. In large structures, the parapets are about eighteen feet in thickness; they often project from the bridge with a cornice underneath. The parapets are parallel for the greater part of their length, in the middle; but at each end they diverge, in order that the increased width of the road thus obtained may render the entrance upon the bridge more free, and unite better with streets, which are commonly wider than bridges. These wide parts of the ends are generally supported by the solid abutments alone.

Piers and abutments are not always built solid throughout. By the judicious use of arches or vaults, the structure may be considerably lightened, without having its strength or durability impaired. The arch-work or hollows of the piers are generally made a little above the spring of the arch. When the abutments are vaulted, care must be taken to do it in such a manner that they will bear the push of the arch as completely as before. The sides of the foundations of abutments should be concave or dished, as this form will conduce the more effectually to their resisting the pressure upon them.

With regard to the superstructure of a bridge, it may be observed, that when the first course of stones has been disposed upon the centering, or wooden frame-work, the remaining courses may be laid with their bedding joints horizontal, in which case they will press upon the first course as a dead weight, without contributing, except by their pressure, to the strength of the arch; or the subsequent courses may be laid in the same manner as the first course, so as to be like a series of arches built immediately upon one another. The latter is the mode most consonant to the laws of strength.

As the principal objects of this work are of a practical nature, we confine ourselves to few and transient sketches of historical research; yet in this place it will be interesting to many, and afford matter for deductions which will supersede the

dryness of further precept, if we notice some of the most remarkable stone bridges which have been erected at different periods.

Of all the bridges of antiquity, that built by the Roman emperor Trajan over the Danube, is allowed to have been the most magnificent. It was demolished by his immediate successor Adrian, and the ruins are still to be seen in the middle of the Danube, near the city of Warhel, in Hungary. It had twenty piers of stone, and each pier was one hundred and fifty feet high above the foundation, sixty feet in breadth, and one hundred and seventy feet distant from one another, which was the span or width of the arches, so that the whole length of the bridge, exceeding fifteen hundred and ninety yards, was nearly one mile.

In France, the Pont de Garde is a very bold structure; the piers being only thirteen feet thick, yet serving to support the immense weight of a triplicate arcade, and joining two mountains. It consists of three bridges, one over another; the uppermost of which is an aqueduct.

The bridge of Avignon, which was finished in the year 1188, consists of eighteen arches, and measures thirteen hundred and forty paces, or about one thousand yards in length.

The famous bridge at Venice, called the Rialto, has been usually regarded as a master-piece of art. It consists of only one very flat, bold arch, nearly one hundred feet span, and only twenty-three feet high above the water. It was built in 1591. Yet such structures sink to insignificance when compared with a bridge in China, built from one mountain to another, consisting of a single arch, six hundred feet long, and seven hundred and fifty feet high; whence it is called the flying bridge.

London bridge was built about the commencement of the thirteenth century. It consisted at first of twenty arches, each of them only twenty feet wide; but the two middlemost were thrown into one in 1758, and another next one side is concealed or covered up. It is nine hundred feet long, sixty feet high, and seventy-four feet wide. The piers are from twenty-five to thirty-four feet broad, with sterlings projecting at the ends; so that the great water-way, when the tide was above the sterlings, was four hundred and fifty feet, scarcely half the breadth of the river; and below the sterlings, the water-way was reduced to one hundred and ninety-four feet, before the opening of the centre. At the time the two middle arches were thrown into one, the houses which had been erected upon the bridge were removed, and various other alterations and repairs undertaken at an expense of £80,000. But so large a sum is still annually

required to keep it in repair, that the preservation of it, instead of erecting a new one, may be considered an act of national improvidence. In consequence of the water-way being so much contracted, the tide, at its ebb and flow, rushes through the arches with such prodigious violence, as to occasion a cataract exceeding the height of four feet, and which prevents or renders highly dangerous the passage of boats. The fall of the water passing through Westminster bridge is only one inch.

The longest bridge in England, is that over the Trent at Burton, built in the twelfth century, of squared free-stone. It is rather low, but strong, and contains thirty-four arches. Its whole length is fifteen hundred and forty-five feet.

One of the most singular bridges in Europe, is that built in the year 1756, over the Taaf, in Glamorganshire, by William Edward, a poor country mason. It consists of only one stupendous arch, which though only eight feet broad, and thirty-five feet high, is no less than one hundred and forty feet span, being part of a circle of one hundred and seventy-five feet in diameter. It is the last of three bridges erected on the same spot by the same person, and it deserves to be mentioned, were it only to record the amazing perseverance of the builder, under very discouraging circumstances. The first bridge he erected consisted of two arches, and he was bound to uphold it for seven years. It was swept away before the expiration of the term, by a flood, that brought down a prodigious mass of floating materials, which obstructed the progress of the torrent through the arches. Edward, whose perseverance increased, and whose genius expanded, under his misfortunes, determined to prevent the recurrence of a similar event, from the like cause, by making only one arch. The first bridge attempted upon this plan, sprung at the crown, and fell before it was finished, from the great weight of the end. This severe blow again called forth the resources of his ingenuity; he disdained to give up the project of having one arch only, but guarded against his late accident, by making the ends of the bridge hollow, and thus he succeeded.

Of modern bridges, those of Westminster and Blackfriars, over the Thames, at London, are esteemed the two finest in Europe. The former is upwards of four hundred yards long. It consists of thirteen large and two small arches, all semi-circular, with fourteen intermediate piers. The arches all spring from about two feet above low-water-mark. The middle arch is seventy-six feet wide, and the others on each side decrease always by four feet at a time. The two middle piers are each seventeen feet thick at the springing of the arches; and the others decrease

equally on each side by one foot at a time; every pier terminating with a salient right angle against either stream. This bridge is built of the best materials, and in a neat and elegant taste, but the arches are too small for the quantity of masonry it contains. It was begun in the year 1738, and opened in 1750. It was executed at an expense of £389,500.

Blackfriars' bridge, which is nearly opposite the centre of the city of London, was begun in 1760, and completed within eleven years from that time. It is an exceedingly light and elegant structure; but the materials do not seem to have been well selected, as some of the arch-stones are already decaying. It consists of nine elliptical arches. The centre arch is one hundred feet wide, and those on each side decrease in regular gradation, to the smallest, at each extremity, which are seventy feet wide. Its length, from wharf to wharf, is about nine hundred and ninety-five feet. The extrados is a portion of a very large circle, of convenient passage over it. It cost £150,840. This amount being so much less than the cost of Westminster bridge, even after making an ample allowance for the greater length of that bridge, is a proof of the advantage of few and elliptical arches over many and semi-circular ones.

Miscellaneous Remarks relative to Building.

Under the present title, we shall include a variety of particulars, either not belonging, or not exclusively belonging, to Masonry or Bricklaying. Under the first head of this subdivision of the chapter on Building, the earliest notice seems due to a sketch of the general rules proper to be observed with respect to the

Situation and Plan of Houses.

With regard to situation, when the person who is intending to build enjoys the advantage of choice, the proximity of marshes, fens, of a boggy soil, or stagnant water, should be avoided. If a river be very near, the site of the house should be on elevated ground, so as to be out of the reach of the unwholesome fogs and mists arising from it early in the morning. A neighbourhood where cattle thrive, and where the inhabitants are healthy and cheerful, or are remarkable for their longevity, may be regarded as possessing a salubrious air. The most essential requisites of a good situation, or those which are most conducive to health, being obtained, minor advantages may be regarded according to their importance. Abundance of water, fuel, and ways of easy access to arrive at the house;

are conveniences of lasting value. The advantages of a situation, with regard to prospect, are of a more problematical nature, as they are so differently valued by different persons. A man of taste, will, however, undoubtedly prefer a spot, the prospect from which is most agreeably diversified in the distribution of its land, wood, and water; and those who have little or no relish for the charms of nature, will perhaps consult their own comfort more than they may be aware of, by making the same choice. There are very few so obstinately morose, as to be uninfluenced by the opinions of others; and to observe those about them, particularly visitors, warm in their admiration of the surrounding scenery, may create a beneficial complacency which they would otherwise want.

Trees at a little distance from a house are better than hills, as they yield during the day, in summer, a cooling, refreshing, sweet, healthy air; and, in winter, break and diminish the keenness of the winds. Hills on the east and south side are the most inconveniently situated. If the site of a house be low, the first floor should be set so much the higher. Cellars contribute to the dryness of a house, if the ceilings and floors be good.

With respect to the situation of the parts of a house, the studies, libraries, and chief rooms, particularly the bed-chambers, should face the east; those offices which require heat, as kitchens, brewhouses, bakehouses, and distilleries, should have southern aspects; and those which require a cool fresh air, as cellars, pantries, dairies, granaries, a northern one, which is also proper for galleries, paintings, museums, &c. which require a steady light.

When a situation has been fixed on, the plan and elevation of every part should be made by some person well acquainted with the theory and practice of building. A skilful architect will not only make the structure handsome and convenient, but will save the great expenses often incurred in rectifying the blunders of hasty and injudicious management. For a small building, the elevation of each front, with a plan, may indicate with sufficient correctness, its ultimate advantages; but for a large mansion, or structure of any description consisting of many complex parts, the most certain way to prevent mistakes, is to have a perfect model of the whole made to a regular scale. In order that such a model may not mislead the judgment by pleasing the eye, it should be made of plain wood, of one colour.

Lodges and small houses, standing alone, have an agreeable appearance when of a cubical figure; but large mansions of this shape look rather clumsy; an oblong is therefore commonly

preferred, care being taken not to make the plan so long as to lose much room in the passages which will be required, and which will be difficult to light. When the length of a mansion does not exceed the breadth more than one-third, the proportion is good.

Of Rooms.

The principal objects to be regarded in the arrangement and proportions of rooms, are doubtless those of conveniency, and their adaptation to health. Rooms, the plan of which are rectangular, give the greatest facility to convenience of arrangement, without the disadvantage of losing the space rendered unavoidable by adopting circular or other curved forms; but with regard to health, the height of a room should at least be ten or twelve feet, and this point should be regarded even in apartments too small to render such an elevation proper in an architectural point of view. A square is an agreeable form, but is most proper for rooms not exceeding a moderate size, as it cannot well, if very large, be completely lighted from one wall, and the company, while ranged on each side, are too far apart. For spacious apartments, a rectangular parallelogram or oblong is a more convenient figure, and, with regard to beauty, every variation in the proportion, from nearly a square to a square and a half or sesquialteral, may be employed. If the length of the plan be extended materially beyond a sesquialteral, the apartment obtains rather the appearance of a passage or gallery, and it becomes impossible to adjust the height so as to suit both the length and breadth. In square rooms of the first story, the height may be from four-fifths to five-sixths of the breadth of the side; and in oblong rooms, the height may be equal to the width. An error in favour of height, is preferable to making a room too low.

The height of rooms on the second story may be one-twelfth part less than that of the chambers below: and if there is a third story, divide the height of the second into twelve equal parts, of which take nine for the height of such rooms.

An eligible length for galleries is five times their breadth, and they should rarely exceed eight times their width in length; their height may exceed their breadth in the proportion of a third or even three-fifths, according to their length.

As, however, in modern houses, all the rooms of the same story are commonly of the same height, and convenience requires them to be of different sizes, according to their use, it follows that the best proportion of the height to the other dimensions, cannot always be observed, without incurring some

extraordinary expense. Where expense is not a hinderance, the height of the story may be suited to the principal rooms, and the middle-sized rooms may be reduced by coving the ceilings, with a flat in the middle, or by groins or domes, which will add to their beauty, independently of bettering their proportions.

Precautions should be taken to prevent the effluvia from the kitchen, brewhouse, and other offices, from penetrating to the bed-chambers and dining rooms. The most difficult object to attain of this description, is to prevent the effluvia of the kitchen from annoying the dining-room, to which the access from it should be as easy and short as circumstances will allow, for the convenience of the servants waiting at table. In country mansions, which admit of the greatest liberty of plan, and where the kitchens are above ground, this may generally be done, by such an arrangement of the doors and passages of communication, that no current of air from the kitchen can proceed directly towards the dining-rooms. But in town houses, where the kitchen is beneath the parlour floor, and therefore not only far nearer in point of situation (though not perhaps of access for persons) than it is usually placed in the country, but on a lower level, the lighter warm air, charged with the smell of the various operations of cookery, is apt to be felt above, from its disposition to ascend. It may, however, be effectually removed by a small separate funnel, carried up in the stack with the rest, and next to that of the kitchen. This funnel, to be used for no other purpose, must have its throat or lower opening level with the ceiling of the kitchen. The lighter air, charged with the vapours of the cooking, will then pass off into the external atmosphere by this aperture, instead of accumulating under the ceiling of the kitchen, until it forms a stratum as low as the top of the kitchen door, and then ascending through the house by the stairs and passages. The opening of this funnel or pipe may be closed by a hinged door, when no operation is going on in the kitchen which can create a disagreeable smell.

Every chamber in a house should, if possible, have a fire-place, the place of which, in those employed as bed-rooms, if they are not very spacious, should be about two feet or two feet and a half out of the middle, to allow room for the bed. In apartments of twenty or twenty-four feet a side, this arrangement need not be studied, as the bed can without it be placed sufficiently far from the fire.

Chimneys.

That no apartment can be comfortable which is incommoded with smoke, will not be contradicted; yet we find a very general disregard of the precautions which would secure a strong draft up the chimney. Masons and bricklayers follow their own fancy or judgment, which are often influenced by their convenience, or by local customs, with little regard to rational principle. It frequently happens that the smoking of chimneys is occasioned by their being carried up narrower at the top than below, or by their having one or more sharp angular turns. When chimneys are constructed in a pyramidal or tapering form, and are besides left rough, or unplastered, with stones or bricks projecting into them, as well as the mortar pressed from the joints in the wall, their smoking is almost certain. The air, rarefied by the fire, passes up a chimney with the smoke; but as it recedes from the impelling power, or fire, it moves slower, and requires a greater portion of space to circulate through; if, then, the upper part of a chimney, instead of being wider than below, be contracted, and if the roughness of the walls concur at the same time to increase the obstruction, it is no wonder that the smoke, taking the path of least resistance, should find its way into the room, whenever assisted by a current from above. It may be urged, that a chimney wider at the top than below, allows the wind more liberty to blow down; but it must be considered, that the wind having no adequate resistance from above to overcome, must necessarily return, and thus facilitate the free egress of the smoke. On the other hand, when a current of air rushes down a pyramidal chimney, it becomes confined or wedged in, and if urged by a constant wind, the rarefied air from the fire cannot make head against it, and therefore the smoke bursts into the room.

Experiments, in endless variety, and often at great expense, have been made to prevent or cure smoky chimneys: we shall notice some of the most simple and efficient; but it will be proper to explain, in the first place, some of the terms which are used in speaking of chimneys. The aperture from a chimney into the room, is called the *fire-place.* The projecting parts of the wall, on the right and left of the fire-place, are called *jambs.* The head of the fire-place, resting upon the jambs, is called the *mantle.* The mantle, and the whole side of the chimney above it up to the top, are called the *breast.* The side of the chimney, called the breast, being pointed out, the application of the term *back,* to the opposite side, explains itself. The sides of the fire-place contained between the jambs and the back, are called *covings.* The *throat* is that part of

the opening immediately above the fire, and contained between the mantle and the back.

When chimneys are bounded on the top by a zigzag line, so as to resemble the teeth of a saw, they are found to be far less liable to smoke than those in other respects under the same circumstances; and in a great variety of cases, the cheap and easy expedient of altering the tops of smoky chimneys to this form, has been attended with complete success. The partitions in a stack should be indented as well as the outside wall.

The fire-place is generally an exact square. Its height, in large rooms, is often very properly made less than a square, and in small rooms, particularly when the chimney is in a corner, it is rather more. In rooms from twenty to twenty-four feet square, or of equal area, it may be from four feet to four feet and a half broad; in rooms from twenty-four to thirty feet square, it may be from four and a half to five feet; and in rooms still larger, it may be extended in a similar proportion to six feet. If much beyond six feet, whatever may be the size of the room, the effect will not be good; for if the fire be proportionate, it will excite rather the idea of a furnace. Two fire-places will certainly be better than one of such overgrown dimensions. As to the effect of the form of this aperture on the draft, its breadth is not very important, provided it be not so narrow as to prevent the covings from standing with their greatest power of reflection towards the room; but the height should seldom exceed two feet six inches to the under side of the mantle. The throat should not be more than four or five inches wide; but should be contracted by a part moveable at the back, when the chimney requires sweeping. The nearer the throat is brought to the fire, the stronger the draft will be. For fire-places about three and a half feet wide in front, the flues of chimneys, above the throat, are usually made equal to about twelve inches square; and the general rule is, to make the area of the horizontal section of the flue, equal to the area of the horizontal section of the fire. If the flue were smooth and circular, this mode of proportioning its size, would doubtless be found to allow it unnecessarily large. Where bends are required in a flue, they should be in a curved, and not an angular direction. High chimneys always draw better than low ones, as, in proportion to their length, the influence of the wind extends a shorter way down them. An apartment made wind-tight, by listing the doors and other contrivances, is liable to be incommoded with smoke, from the want of draft, even when the chimney is constructed in the most proper manner: a few

minute holes, communicating with the exterior, will, in such cases, constitute an effectual remedy.

Another method of increasing the draft of a chimney, consists in setting the grate, if a Bath stove, eleven or twelve inches from the fender; and in cutting away the back of the chimney, so as to leave a space of two inches between it and the back of the grate. If the grate be of the common form, the sides should be filled up with brickwork. By this construction the air that passes behind the back of the grate, assisting to impel the smoke, prevents its bursting into the room. —That a chimney clogged with soot will be apt to smoke, is so well known, as to require no notice here.

The evils attending the practice of cleaning chimneys by means of climbing boys, are of the first magnitude. The degraded situation of the children in this employment, so destructive to health at any period of life, but especially in early youth, has often and strongly excited the commiseration of philanthropical men, and many schemes have been proposed to render their ascending unnecessary, and thus abolish a practice so offensive to humanity. Of these plans, the most feasible consists in the use of brushes, which are drawn up and down by men at the top and others at the bottom, or are pushed up from the bottom, and drawn down by persons within the apartment. The former method is inconvenient and expensive; the latter, which is the invention of Smart, is often practised, and has justly received much approbation. The rods by which the brush is pushed upwards, are made hollow and in short lengths, and are connected together by a cord passing through them. As soon as the lower end of the first rod is pushed about the height of the mantle, another rod is slipped over the cord, and the lengthening of the whole is thus continued, till the brush clears the top of the chimney, where it spreads itself out, and is prevented from contracting by a spring; so that the soot is brought down along with it. But as long as the practice is continued, of making chimneys square, crooked, and rough, it is to be feared that no sweeping apparatus can be contrived which will be found completely successful. Inventions recommended merely by their humanity, are often so slow in their progress towards general adoption, that an eminent service will be rendered to society, by the man who makes the convenience and interest of individuals conspire with their benevolence, to promote the purpose before us. The Author of the treatise on Architecture in this work, has furnished us with the following remarks on the present subject, which we have pleasure in laying before the

public. He commences with a few observations on the late rapidly extended use of iron:

Amongst the various improvements of modern times, perhaps few have been more really beneficial than the use of metals, for purposes to which, only half a century back, they were hardly thought applicable. It is perhaps not generally known, that the great variety of articles of fittings now constantly kept in ironmongers' shops, in the remotest villages, were hardly known in country places at the beginning of the last century; but wherever a house was built, its bolts and latches were mostly of wood; its windows, if sashes, were massive, and if one sash run, the sash-cord ran over a wooden pulley; and many other minute fittings were either of wood, or, if of metal, were individually made by the adjacent smith, who produced a clumsy article at a great waste of time and labour. We now see the use of iron and brass extensively superseding timber and stone in the most advantageous manner. At Eaton Hall, the magnificent mansion of Lord Grosvenor, near Chester, the tracery of the windows, many shields, a stair-case, and a variety of ornaments, are of cast iron. A large portion of tracery pannelling, for a terrace balustrade, are of the same material, and being painted and sanded, have all the beauty of stone. Hollow Grecian balustrades, for a public building in Ireland, have been made of iron, in Liverpool. Two patents have been taken out for roof framings of iron, one of which, at least, that of J. Cragg, Liverpool, is particularly remarkable for its simplicity, and the beauty of its execution. This gentleman also executes stair-cases of iron, in so accurate a manner that they may be put up at any place in a few hours. Cast iron bridges have long been deservedly celebrated, and the dearness of wood, and the supposed inefficiency of the patent-stone pipe, have caused cast iron water-pipes to be used in London, and many other places. Cast iron has also been advantageously used for beams and their supports in a large way, the Trustees of the Duke of Bridgewater's canal having used it for beams in a new warehouse at Liverpool, of more than thirty feet clear span; and the Carron Company have used some excellently arranged hollow iron stanchions in a new warehouse at Liverpool.

There is yet another purpose, for which iron seems so well adapted, that it deserves at least a fair trial; it is that of cast pipe for chimneys. The present mode of building chimneys is not only extremely unsafe, but also takes up a great deal of room; and from their being square, there is a great difficulty in cleaning them thoroughly, except by climbing boys, or, as is

frequently practised, by purposely firing them. Smart's apparatus does not completely answer, because the corners which contain most soot do not get swept completely, and are often not touched. Another objection to ordinary brick square chimneys is their smoking, or, in other words, not drawing; an evil not considered, by those who suffer from it, of the most trivial magnitude. All these inconveniences might be remedied by using for chimneys cast iron pipes three-eighths of an inch thick, and when once the utility of the plan became known, the article would be as common in iron shops as fronts of grates. The present openings into the room are built far too large, and are now generally contracted by various means when the grate is set, but while the present arrangement of brick chimneys for climbing boys remains, they cannot well be much altered; but if iron pipe were used, an iron fire-place top would be cast for the pipe to fit into, and would of course be made of various sizes and shapes like grate fronts, and iron articles in general, cast by the Carron Company and other founderies.

More clearly to exemplify the advantages of this invention, it will be proper to detail the arrangements necessary. Prejudice will at first perhaps require the pipe to be eight inches in diameter, though there is little doubt that seven, six, or even five inches diameter, would be amply sufficient for the largest fire. However this may be, it should be cast in lengths of from three to five feet, which at three-eighths of an inch thick would render the pieces of a manageable weight; they should be carried up as close as possible to each other, and as four inches of brick-work is more than enough on each side of them, in walls of two bricks thick, they would cause no projection into the apartment. The interstices between the bricks and pipe should be filled with earth, or, what would be still better, rubbish and liquid cement. A bevel joint, *a*, fig. 15, pl. I. might be made to the pipe, to fit so closely that no crevice would be left to lodge soot, when the cement surrounded the exterior.

If one, or indeed all the chimneys in a stack, constructed upon this plan, were to get on fire, it would be of little consequence, as the heat could never be so great as to act through the pipe and such a solid mass as the stack would be. The soot would not lodge in such chimneys as in the common ones, for in a round chimney the draft would clear more smoke out of the chimney before it was condensed; and when they required cleaning, Smart's apparatus would sweep them completely.—When a house with ordinary chimneys is burnt, the stack usually falls down, tearing the walls, and rendering it

necessary to rebuild them; but if a house with an iron-pipe stack was burnt, it would not only in all probability stand, but act as a buttress to sustain the walls; or, in case it fell, the greater part of the pipe would remain as fit for use as at first. Although it may be least trouble generally to leave the breadth of half a brick round the pipe, yet, in small buildings, and in cases where room is wanted, a flat brick would, there is no doubt, be quite sufficient for all purposes of safety. In all cases, too, where iron-pipe may be used, the labour of plastering chimneys will be saved, which, though in many places omitted, is done to all well-built houses.

The saving of room which would be produced by the use of iron-pipe, in a stack of four eight-inch chimneys, will be immediately seen by the inspection of fig. 13, No. 1 and 2, pl. I; and fig. 14, No. 1 and 2, exemplifies the same thing with respect to a stack of five chimneys. If nine inches be allowed for the exterior diameter of the pipe (and such an allowance will be enough for all contingencies,) it may be carried up, in all walls exceeding two bricks thick, without any projection into the apartments. In the corners of a two brick, or even a one and a half brick wall, there is sufficient room, as may be seen by referring to the plans of such walls in pl. I, to carry up such a chimney, which would rather increase than diminish the strength of the wall. By the figures of the plate just referred to, it will be seen that nearly one-half of the space taken up by chimneys in the common way will be saved, under circumstances the most unfavourable to shewing the advantages of the new plan; for the diameter of the pipes is reckoned at the largest that can be required; and the brick-work surrounding the square chimneys at the thinnest it can with any propriety be made.

The increased expense of round work, either in brick or stone, is probably the principal reason that round chimneys are not in general use, though the advantages of them, particularly in being free from the currents or eddies of air occasioned by square chimneys, are not unknown to intelligent builders.

Iron pipe, it is well known, answers perfectly well for stoves, and the portable furnaces of chemists, although the area of it is seldom more than half that of the fire, and the quantity of air required to maintain the vehement heat which can be excited at pleasure, occasions a much greater draft than that of ordinary domestic fires of twice the size. Hence the above plan only proposes the extended use of a kind of chimney, the adequateness of which is already proved.

Doors.

The ancients, according to Vitruvius, frequently made their doors rather narrower in breadth at the top than at the bottom. These trapezoidal doors were probably adopted from their having the property of closing themselves, and in modern times they are useful besides as the simplest mode of raising the door, in the act of opening, above the floor, in order to keep it clear of the carpet. There are examples of them in the Bank of England; but they are not often introduced by architects.

Doors are varied in their dimensions according to the height of the story and the magnitude of the building in which they are placed. In private houses, they can rarely with propriety be made wider than four feet, and in general three feet will be sufficient. For small doors, when the height is to the breadth in the ratio of seven to three, the proportion may be considered good; but the height of large doors need not be more than double their breadth. The entrance doors of palaces and the mansions of noblemen, where much company resort, are often made from four to six feet wide; and those of public edifices may be from six to ten feet wide. Doors much exceeding three feet in width, should have folding leaves. In modern houses, it is not uncommon to have large folding doors, the opening of which serves, instead of removing a whole partition, to throw two rooms into one. In such cases, the width of the aperture will generally be of less height than twice its breadth, as all the doors of the same story are commonly of the same height.

When the principal door of entrance is in the middle, its communication with every part of the building is not only the most readily effected, but it contributes so much to the symmetry of the front, that when the plan renders such a position inadmissible, a blank door is frequently substituted for a real one, which is then made in the most convenient place. The entrance doors of stately houses, are frequently adorned with porticoes, in the Grecian or Roman taste; but the most common mode of adorning entrance doors, is to surround them with an architrave, surmounted with a cornice, or with a frieze and cornice forming a complete entablature. These decorations are made of stone, wherever a suitable kind can be had at a reasonable price.

Windows.

In determining the number and size of windows, regard must be paid to the destination, local position, and elevation of the building, as well as to the cubature and height of the story

in the rooms to be lighted, and the thickness of the walls. With respect to private houses, though considerable latitude may be allowed in the determination of this subject, still there are limits which cannot be disregarded without losing the beauty of proportion, and the convenience of a due quantity of light. In general, the piers should not be of less breadth than the apertures, nor more than twice such breadth. The windows in all the stories of the same aspect, should be of the same breadth, unless a variation be required from this rule for the convenience of particular offices in the lowest story. The laws of symmetry and strength alike require them to be exactly one above another; this practice, so strangely neglected by our ancestors, is now, indeed, duly attended to. The apertures of windows should widen inwards on each side, by which means the quantity of light admitted will be nearly as much as if they were externally of the same size as the increased internal dimensions.

To determine the aggregate area of the windows proper to be made in an apartment, extract the square root of the cubature of such apartment, and the quotient will be the answer. For example, suppose the room to be forty feet long, thirty feet broad, and sixteen feet high, then $40 \times 30 \times 16 = 19200$, which product is, in feet, the cubature sought, and the square root of it, neglecting a small remainder, is one hundred and thirty-eight feet for the aggregate area of the apertures. One hundred and thirty-eight feet will make four windows of a handsome size and shape, adapted to the apartment in question; and if divided accordingly into four parts, thirty-four feet and a half will be the area of one of them. The area thus obtained, when set out, for a ground floor, according to the customary rule, which allows rather more than two squares in height, each window may be about eight feet eight inches high, by four feet broad. By the same rule, the dimensions of the apertures of windows for rooms of any other cubature may be determined.

The sills of windows have been mostly made from three feet to three feet six inches distant from the level of the floor, as at that height they formed a convenient parapet to lean upon; but the French fashion having been introduced, of having the windows, at least in the principal drawing rooms, down to the floor, window-sills are now, partly in imitation of it, made lower than formerly, and in ordinary dwellings are frequently not higher than two feet, and in the extreme not more than two feet six inches.

It will be proper to remind those who are partial to spacious and numerous windows, and who are not disposed to modify

their choice by motives of economy, that as the aggregate area of the windows is enlarged, it becomes increasingly difficult in winter to keep apartments warm, the heat produced in them being so very speedily communicated through the glass to the atmosphere without. It is for this reason, that in Russia they often make their windows double, and as air is a bad conductor of heat, the stratum of it interposed between the two windows in the same frame, tends very materially to prevent the temperature of the room from being carried off. The cold season is not so severe, or of such long continuance, as to have occasioned the introduction of this practice for front windows into the United Kingdom, but it might be advantageously acted upon with respect to the skylights employed to light staircases, as such windows, when only single, contribute greatly to the speedy dissipation of the warm air which ascends to the top of the house.

The number of windows on each side of the entrance door should be equal, and an odd number of windows in an apartment, when they are all on one side of it, is better than an even number, as it avoids the necessity of having a pier opposite the middle of the floor.

The windows of the principal floor are generally the most enriched. the simplest mode of adorning them, is, to surround them with an architrave, which sometimes has, and sometimes is left without, a frieze and cornice; frequently, the whole of the windows are left plain, except the central one of the second story. When the windows of the principal story have pediments, those of the story immediately above should have architraves surmounted by a frieze and cornice, and those of a next higher story, an architrave only. The sills of all the windows in the same floor should be on the same level.

Stairs.

To unite the requisites which a good staircase requires, namely, convenience in situation and form, with a sufficiency of light, affords one of the strongest proofs of an architect's skill. In stately mansions, the steps should not be less than four, nor more than six inches high; nor more than eighteen or less than twelve inches broad; and the width should not be less than six or exceed fifteen feet. In ordinary houses, the steps are generally made higher, and are almost necessarily narrower, both in width and length; but, while any thing like handsomeness of appearance and convenience of ascent are studied, they should not exceed seven inches in height, nor be less than ten inches broad, and three feet long. Stairs are ascended with more ease when laid somewhat sloping, or a

little higher at the back. The ancients were partial to an odd number of steps; one consequence of which choice was, that the same foot which was placed on the first step was first placed at the top on the landing.

Roofs.

Architects include, under the term roof, not only the exterior covering of a house, but all the beams and other parts necessary to support that covering.

Among the ancients, in those countries where it seldom rained, roofs were made quite flat; but the Greeks, perceiving the inconvenience of this form, deviated from it a little, by inclining their roofs, as appears from several ancient remains, about one-eighth or one-ninth part of the span. The Romans, who had rather more occasion than the Greeks to provide for the speedy discharge of rain from their houses, made the height of the inclination of their roofs from one-fifth to two-ninths of the span. Among the northern nations of Europe, after the decline of the Roman empire, high-pitched roofs began to be in general request, and that was considered the standard form, the vertical section of which was an equilateral triangle. No part of the art of building has been more subject to caprice, than the height of the inclination, or, as it is usually expressed, the pitch of roofs. In the present day, a great variety of pitch is employed, but the equilateral one is seldom seen. In ordinary dwellings, the pitch of the roof is from one-third to one-fourth part of the span; but mansions and public edifices are still executed in every diversity of style that fancy or particular views can dictate.

High-pitched roofs discharge rain and snow more quickly than others; they are also not so easily stripped by the wind; the rain is not so easily blown between the slates, and from their approach towards perpendicularity of pressure, they are not so great a burden to the walls. They are, however, more expensive than low roofs, as they require longer and stronger timbers; and from their greater surface, they require a larger quantity of the covering material: but though low roofs have the advantage in point of cheapness, they require large slates, and great care of execution.

The roof is one of the principal ties of a building, when skilfully executed, in connecting the exterior walls. Some idea may be formed of the success with which scientific knowledge and experience may be employed in the construction of roofs, when it is observed, that roofs have been constructed sixty feet wide, although they have not contained a single piece of timber more than ten feet long and four inches square.

Fig 1.

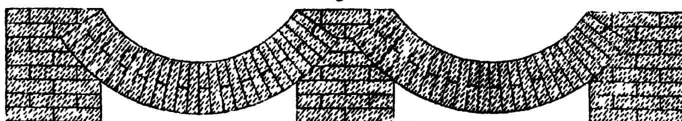


Fig 2.

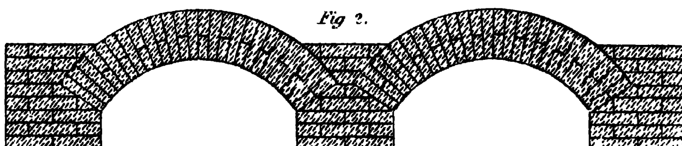


Fig. 3

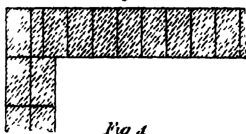


Fig 8.

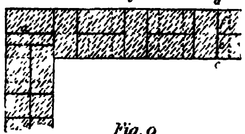


Fig 4

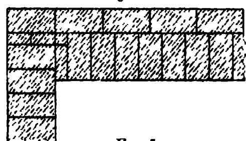


Fig. 9

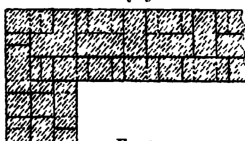


Fig. 5

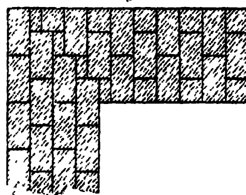


Fig. 10

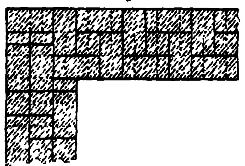


Fig 6.

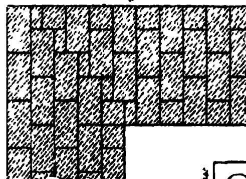


Fig 11.



Fig 12

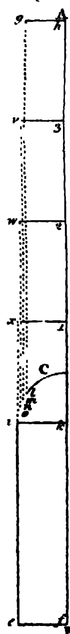


Fig. 17

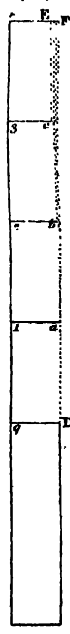
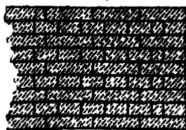
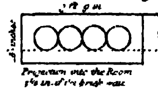


Fig. 7.



Nº 1. Fig. 13. Nº 2.



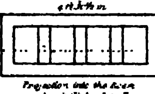
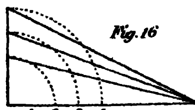
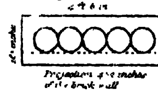


Fig. 16



Nº 1. Fig. 14. Nº 2.



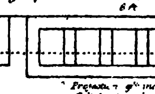
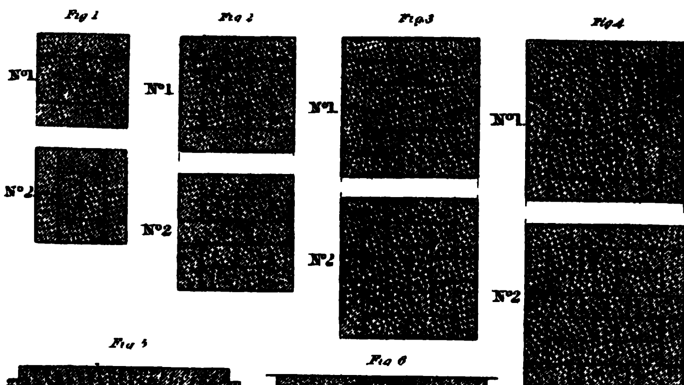


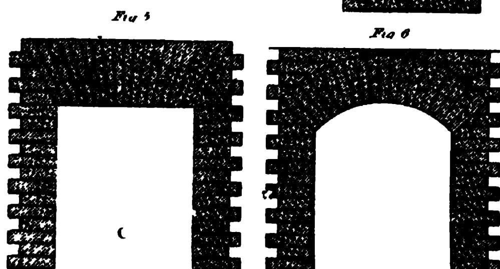
Fig 15.

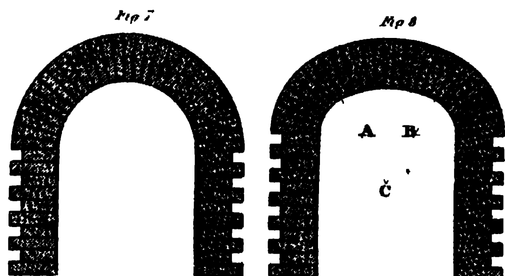


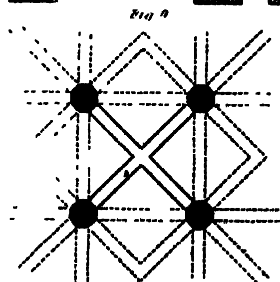
J. Smith del. S. Porter sc.

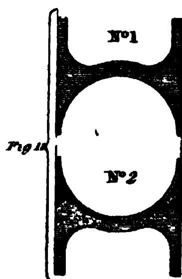
PL. II.

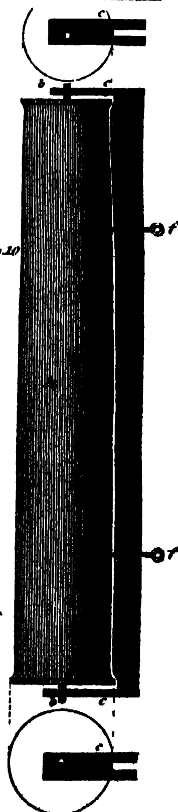












Drawn by J. Smith

Engraved by Jas. Davies

FISHER SON & Co. LONDON 18..

In determining the pitch of rafters, when mere fancy is not to be our guide, the nature of the intended covering should be taken into consideration, and the inclination proportioned accordingly. The following rules may be observed with propriety:

For *Lead.*—Divide the width first into two parts, see fig. 16, pl. I. and one of these parts into four, as 1, 2, 3, 4; with two of these parts, describe a quarter circle, 2, which gives a proper pitch or slope to be covered with lead, and is called a pediment pitch.

For *Pantiles.*—Divide the width as before into two parts, and one of these two parts into four, as 1, 2, 3, 4; with three parts, describe a quarter circle, 3, which gives a proper pitch for use.

For *Plain Tiles.*—Divide the width into two parts; with one of them make a quarter circle, which gives a pitch or slope proper for the roof.—The lighter the covering material, the lower the roof may be, and therefore the pitch for slates, may be the same as that for the covering which the particular quality used most nearly approaches to in weight.

Tiles, though extensively used in many parts of the country, constitute a very heavy covering for houses, and, what is still worse, they injure the timber upon which they are laid, and tend to make a house damp, from the facility with which they are penetrated with moisture. The following experiment, by the bishop of Llandaff, decisively proves their great porosity, and their inferiority to slate. The Bishop observes, that sort of slate, other circumstances being the same, is esteemed the best which imbibes the least water; for the imbibed water not only increases the weight of the covering, but, in frosty weather, being converted into ice, it swells and shivers the slate. This effect of frost is very sensible in tiled houses, but is scarcely felt in those which are slated; for good slate imbibes but little water; and when tiles are well glazed, they are rendered in some measure, with respect to this point, similar to slate. He took a piece of Westmoreland slate, and a piece of common tile, and weighed each of them carefully; the surface of each was about thirty square inches. Both the pieces were immersed in water for about ten minutes, and then taken out and weighed as soon as they had ceased to drip. The tile had imbibed above a seventh part of its weight of water; and the slate had not imbibed above a two-hundredth part of its weight; indeed the wetting of the slate was merely superficial. He placed both the wet pieces before the fire; in a quarter of an hour the slate was become quite dry, and of the same weight it had before it was put into the water; but the tile had lost only about twelve grains of the water it had imbibed, which was, as nearly as could be expected, the very same quantity that had been spread over

its surface; for it was the quantity which had been imbibed by the slate, the surface of which was equal to that of the tile. The tile was left to dry in a room heated to sixty degrees, and it did not loose all the water it had imbibed in less than six days. If, then, tiles imbibe a seventh part of their weight of water in ten minutes, and cannot be deprived of this water without a degree of heat equal to sixty degrees continued for six days, it must be obvious that a roof covered with them, can, in this country, seldom be dry. The timbers also of the roof must be calculated to support their weight in their wet state.

The finest sort of blue slate, which is obtained in the neighbourhood of Kendal, is sold there for 3s. 6d. per load, which comes to £1. 15s. per ton, the load weighing two hundred weight. The coarsest sort may be had for 2s. 4d. per load, or £1. 3s. 4d. per ton. Thirteen loads of the finest sort will cover forty-two square yards of roof, and eighteen loads of the coarsest sort will cover the same extent. Hence there is half a ton less weight upon forty-two square yards of roof when the finest slate is used, than when it is covered with the coarsest kind, and the difference in the expense of the material is only 3s. 6d.; yet as fine slate owes its lightness, not so much to a difference in the quality of the stone from which it is split, as to the thinness to which it is reduced, it is inferior to the heavier kind in point of durability.

The following statement shews the average weight of the covering laid upon forty-two square yards of building, according to the material employed:

Copper	4*cwt.*
Fine Slate	26
Lead	27
Coarse Slate	36
Tiles	54

Such are the advantages of slate as a covering, that wherever it can be procured without much land carriage, it obtains the preference of all other materials. Its durability is so great, that it has been known to continue sound and good for centuries; but all kinds of it are not equally excellent in this respect. Its most usual colours are white, brown, and blue, and the colour affords some index to the quality of the slate. The light blue sort is always the least penetrable to water, which the deep black blue is apt to imbibe rather freely. Several methods may be practised to ascertain the goodness of slate, when not brought from a quarry of well known character. If a slate, when struck sharply against a large stone, produce a complete sound, it is a mark of goodness: and if it does not

shatter before the edge of the zax, or instrument used for hewing it, the criterion is decisive. Another method is, to place the slate lengthwise and perpendicularly in a tub of water, about half a foot deep, care being taken that the unimmersed part of the slate be not in any way accidentally wetted. Let it remain in this state twenty-four hours: at the end of that time, if the slate be good, it will not have drawn water more than half an inch above the surface of that fluid, and that perhaps at the edges only, where the texture has been a little loosened in the hewing; but a spongy defective stone will draw water to the very top. Another mode of trial, on the result of which full reliance may be placed, is to weigh two or three of the most suspected slates, and note their precise weight; then immerse them entirely in water for twelve hours: take them out, wipe them as clean as possible with a linen cloth, and if their weight differs not, or differs but very little from what it was at first, they may be considered good; a drachm in a dozen pounds is allowable, but not more. The principal reason of the inferiority of the slates which imbibe much moisture, being that they are shivered by frost; when none but a porous kind can be easily obtained, they might doubtless be improved by the application of tar, as already mentioned for tiles, when treating of the manufacture of the latter article.

John's tessera is perhaps the best of those artificial compositions which are designed for roofing, and it certainly has advantages of the first class. It is cheaper than any covering hitherto known; it is superior in lightness and evenness of surface to lead, and is said to equal that metal in point of durability. It is equally adapted to the flat roof intended to be walked on, and to angular roofs. The roofs intended to be covered with it must in all cases be boarded as for lead, except that a less thickness of timber will suffice. For a flat roof, it may be laid on three-quarter inch deal; but for an angular roof, half-inch will be sufficient. This roofing, for which a patent was taken out, dated the 22d December, 1806, consists of calcareous stone and tar, with a little of the powder of burnt bones. The sheets are made of an equal thickness by rolling. From the quantity of tar entering into the composition, it may be considered very combustible; but the contrary has been proved by experiment. It is found to resist the effects of heat two or three times as long as lead. Tessera is made in sheets about four feet long, by two feet wide; and the sheets are united by solder of the same composition.

Floors.

Flooring boards are mostly made of fir. The first class are selected free from knots, shakes, sap-wood, or cross-grained stuff; the second class consists of boards also free from shakes and sap-wood, but not from small sound knots; the third class contains the residue of any parcel, or such boards as cannot be included in either of the preceding classes. When an agreement is entered into for the erection of a building, the quality of the boards should be specified, to prevent subsequent disputes. As all boards shrink in the course of time, and as the quantity of their contraction increases with their dimensions, floors which are laid with very broad boards, soon exhibit, at the joints, wide fissures that have an unpleasant appearance. It is therefore the practice in good houses, not only to select the best part of the wood, but to cut the boards into narrow scantlings; so that, if properly seasoned, and laid close at first, their shrinking afterwards is so small as to make no openings of consequence. Boards about five inches broad may be reckoned narrow, but when they measure nine inches or more in the same direction, they must be considered broad.

The manner of jointing flooring boards, and fastening them down upon the joists, is performed in a variety of ways, the most usual of which is, to plane the edges of the board quite square, that is, at right angles to the upper and under surface, and then, placing them as closely to each other as possible, to nail them down from the upper surface. Sometimes, particularly when the wood is known to be insufficiently seasoned, after the first board has been fastened down, the fourth board is secured in like manner, the two intermediate boards are then made somewhat wider than the space to receive them, and forced into their places by jumping upon them. To do this with the most ease and advantage, the intermediate boards are laid aslant, so as to be highest in the middle, and those edges which are placed together being sloped a little, so as to form rather less than a right angle with their respective upper surfaces, they are, by an adequate weight, at once compressed and levelled. The fourth board of the last series becomes the first of the next, and the operation, which is called folding the boards, is repeated till the floor is finished. The nails are driven in a little below the surface of these boards, and the cavity is filled with glazier's putty. But in rooms not intended to be carpeted, and yet where a neat and clean appearance is indispensable, the use of putty must be avoided, and the nails must not be driven in from the top. This object is obtained by doweling the joints, that is, driving

wooden pins into them in the middle of their thickness, and parallel to the surface, in the same manner as the coopers joint the boards forming the ends of their casks. In this case, one-half of each pin entering the edges placed together, the boards, if the dowels be sufficiently numerous and properly placed, cannot rise or sink but in conjunction. The best place for the dowels is in the middle of the space between the joists. In the best doweled work, the nails are concealed when the floor is finished, for they are driven in slantwise through the outer edge only of each board. Sometimes the joints of flooring boards are rabbeted, that they may lap over each other a little way, and sometimes toothed into each other, or, as it is technically expressed, ploughed and tongued. When either of these methods is adopted, the boards are not separated on their contraction so as to leave an aperture between each pair, through which any thing can drop; but such floors are more costly than others, not only on account of the extra labour, but the greater quantity of wood which they require.

It is always desirable to cover a floor with boards in one length; but as this may not always be convenient, when it is not done, the ends of the two boards that meet are called headings. The headings should invariably be upon a joist, and two of them should never be together in the same line.

Before the boards are laid, it is necessary to examine whethe the upper sides of the joists all lie in the same plane. The defect they are most liable to, is that of being depressed in the middle; in which case they must be raised by the addition of suitable pieces, but if found too protuberant, they must be reduced by the adze.

Yellow deal, well seasoned, is one of the best woods that can be selected for floors, and retains its colour for a long time; whereas the white sort, by frequent washing, becomes blackish and disagreeable in its appearance.

In the habitations of the labouring classes of society, the ground floors are often made of a kind of mortar. The best materials for this purpose are two-thirds of lime, one of coal-ashes, and a small portion of clay. These ingredients are to be well tempered with water, left to subside for a week or ten days, and then well worked up again. This operation should be repeated in the course of three or four days, till the mixture becomes smooth and glutinous, when it is fit for use. After the ground is made perfectly level, the composition is to be laid on to the depth of two and a half or three inches, and carefully smoothed with a trowel. The hottest season of the year is the most proper for applying this composition, which, when completely dried, will make a most durable floor.

Proportions of Timbers, &c.

In the treatise entitled the "British Carpenter," already referred to, are given the following Tables to shew the proportions of timbers for small and large buildings:

PROPORTIONS OF TIMBERS FOR SMALL BUILDINGS.

Bearing Posts of Fir.		*Bearing Posts of Oak.*	
Height	Scantling	Height	Scantling
if 8 feet	4 inc. square	if 10 feet	6 inc. square
10	5	12	8
12	6	14	10
Girders of Fir.		*Girders of Oak.*	
Bearing	Scantling	Bearing	Scantling
if 16 feet	8 inc. by 11	if 16 feet	10 inc. by 13
20	10 12½	20	12 14
24	12 14	24	14 15
Joists of Fir.		*Joists of Oak.*	
Bearing	Scantling	Bearing	Scantling
if 6 feet	5 inc. by 2½	if 6 feet	5 inc. by 3
9	6½ 2½	9	7½ 3
12	8 2½	12	10 3
Bridgings of Fir.		*Bridgings of Oak.*	
Bearing	Scantling	Bearing	Scantling
if 6 feet	4 inc. by 2½	if 6 feet	4 inc. by 3
8	5 2¾	8	5½ 3
10	6 3	10	7 3
Small Rafters of Fir.		*Small Rafters of Oak.*	
Bearing	Scantling	Bearing	Scantling
if 8 feet	3½ inc. by 2½	if 8 feet	4½ inc. by 3
10	4½ 2	10	5½ 3
12	5½ 2½	12	6½ 3
Beams of Fir, or Ties.		*Beams of Oak, or Ties.*	
Length	Scantling	Length	Scantling
if 30 feet	6 inc. by 7	if 30 feet	7 inc. by 8
45	9 8½	45	10 11½
60	12 11	60	13 15

Principal Rafters of Fir.	Scantling		*Principal Rafters of Oak.*	Scantling	
Length	Top	Bottom	Length	Top	Bottom
if 24 feet	5 ins. & 6	6 ins. & 7	if 24 feet	7 ins. & 8	8 ins. & 9
36	6½ 8	8 10	36	8 9	9 10½
48	8 10	10 12	48	9 10	10 12

PROPORTIONS OF TIMBERS FOR LARGE BUILDINGS.

Bearing Posts of Fir.			*Bearing Posts of Oak.*		
Height	Scantling		Height	Scantling	
if 8 feet	5 inc. square		if 8 feet	8 inc. square	
12	8		12	12	
16	10		16	16	
Girders of Fir.			*Girders of Oak.*		
Bearing	Scantling		Bearing	Scantling	
if 16 feet	9½ inc. by	13	if 16 feet	12 inc. by	14
20	12	14	20	15	15
24	13½	15	24	18	16
Joists of Fir.			*Joists of Oak.*		
Bearing	Scantling		Bearing	Scantling	
if 6 feet	5 inc. by	3	if 6 feet	6 inc. by	3
9	7½	3	9	9	3
12	10	3	12	12	3
Bridgings of Fir.			*Bridgings of Oak.*		
Bearing	Scantling		Bearing	Scantling	
if 6 feet	4 inc. by	3	if 6 feet	5 inc. by	3½
8	5½	3	8	6½	3½
10	7	3	10	8	3½
Small Rafters of Fir.			*Small Rafters of Oak.*		
Bearing	Scantling		Bearing	Scantling	
if 8 feet	4½ inc. by	3	if 8 feet	5½ inc. by	3
10	5½	3	10	7	3
12	6½	3	12	9	3
Beams of Fir, or Ties.			*Beams of Oak, or Ties.*		
Length	Scantling		Length	Scantling	
if 30 feet	7 inc. by	8	if 30 feet	8 inc. by	9
45	10	11½	45	11	12½
60	13	15	60	14	16

Principal Rafters of Fir.			*Principal Rafters of Oak.*		
	Scantling			Scantling	
Length	Top	Bottom	Length	Top	Bottom
if 24 feet	7 ins. & 9	8 ins. & 9	if 24 feet	8 ins. & 9	9 ins. & 10
36	8 9	9 10½	36	9 10	10 12
48	9 10	10 12	48	10 13	12 14

The Author of the preceding Tables observes, that though they seem so plain as not to exceed explanation, yet a few remarks might be subjoined with propriety. All binding or strong joists, he then adds, ought to be half as thick again as common joists; that is, if a common joist be given three inches thick,

a binding joist should be four inches and a half thick, although of the same depth.

If it be not convenient to allow the posts in partitions to be square, which is the best form, in such cases, multiply the square of the side of the posts, as here given, by itself: for instance, if it be six inches square, then as six times six is thirty-six, to keep this post nearly to the same strength, find two numbers producing the same amount; as suppose the partition to be four inches thick, then let the post be nine inches the other way, so that nine times four being thirty-six, the area of its horizontal section is the same, and its strength nearly equal to the square post.

Posts that go to the height of two or three stories, need not hold the proportions given in the table, because at every floor they meet with a tie. Admit a post to be thirty feet high, and that in this height there are three stories, two of ten feet and one of eight feet; look for posts of fir ten feet high, their scantling is five inches square, that is, twenty-five square inches, which double for the two stories; and also take that of eight feet high, being four inches, that is, sixteen inches square, all which being added together, make sixty-six inches; so that such a post would be rather more than eight inches square. On occasion it may be lessened in each story as it rises.

All beams, ties, and principal rafters, ought to be cut or forced in framing to a camber, or roundness, on the upper side, and the convexity may be about one inch in eighteen or twenty feet. The reason is, that all timber, partly from its own weight, but principally from the weight of the covering or other burden it has to bear, will swag; and unless prepared in this manner, that it may never become concave, a degree of unsightliness, and often of inconvenience, will be produced.

The joists in floors, the purlines (or timbers into which the small rafters are tenoned in roofs,) &c. should not exceed twelve feet in the length of their bearing, or from support to support. The strong joists of floors should not be at a greater distance than five feet, nor common joists more than ten or twelve inches apart.

According to the experiments of Muschenbroek, fir is able to bear compression in the direction of the length of its fibres, or to sustain as a post, a much greater weight than oak, but is far infe rir to oak when the weight is suspended. In the preceding tables, therefore, the scantlings of fir bearing posts and principal rafters are properly made *less* than those of oak; but for other timbers, particularly for ties, many are of opinion that the proportions of the Author's tables should be reversed, and the scantling which he has assigned to fir should be given to oak.

Building Act.

All the buildings erected in London and the several Parishes within the Bills of Mortality, are subjected to the regulations of an Act of Parliament, of the 14. Geo. III. the main object of which is to lessen the danger to be apprehended from fire. As many of the provisions of this act are of great importance, and deserve to be universally known and acted upon, we shall conclude the subject of Building by an abstract of them. Those which relate to the Carpenter are the following:

Timber partitions between building and building, erected or erecting before the passing of the act, may remain till one of the adjoining houses is rebuilt, or till one of the fronts, or two-thirds of the fronts which abut on such timber partition, is taken down to the bressummer, or one pair of stairs floor, and rebuilt.

Three months' notice of the pulling down of such wooden partition, when decayed or of insufficient thickness, to be given by the proprietor to the owner or occupier of such a house, and if the house be empty, such notice to be stuck up on the front or front door of it.

No timber hereafter to be laid in any party arch, or party wall except for bond to the same; nor any bond timber within nine inches of the opening of a chimney, nor within five inches of the flue; nor any timber within two feet of any oven, stove, copper, still, boiler, or furnace.

The wood work of chimney breasts to be fastened to the said breast with iron wall hooks, spikes, nails, or holdfasts, which must not be driven more than three inches into the wall, or nearer than four inches to the inside of the opening of the chimney.

No timber bearer to wooden stairs let into an old party wall, must come nearer than eight inches and a half to the flue, nor nearer than four inches to the internal finishing of the adjoining building.

No timber to be laid under any hearth to a chimney, nearer than eighteen inches to the upper surface of such hearth.

No timber must be laid nearer than eighteen inches to any door of communication through the party walls of warehouses and stables.

Bressummers, story posts, and plates thereto, are only permitted in the ground story, and may stand even with the outside of the wall, but must go no deeper than two inches into a party wall, nor nearer than seven inches to the centre of a party wall, when it is two bricks thick, nor nearer than four

inches and a half, provided the party wall does not exceed one brick and a half in thickness.

Every corner story post must be of oak, and at least twelve inches square, when employed for the support of two fronts.

Window frames and door frames to the first, second, third, and fourth rate classes, are to be recessed in reveals, four inches at least.

Door-cases and doors to warehouses only of the first, second, third, or fourth rate classes, may be even with the outward face of the wall.

No external decoration to be of wood, except cornices or dressings to shop windows; frontispieces to door-ways of the second, third, and fourth rate classes, and covered ways or porticoes to buildings; but not to project beyond the original line of the house in any street or way. Such covered way or portico not to be covered with wood; nor such cornice, covered way, or roof of the portico, to be higher than the under side of the sill to the windows of the one pair of stairs floor. No flat gutter or roof, nor any turret, dormer, or lantern light, or other erection placed on the flat of the roof belonging to the first, second, third, fourth, and fifth rate classes, to be of wood.

No wooden water tanks must be higher from the ground than the tops of the windows of the ground story.

Those provisions of the Act which relate to the Bricklayer are the most numerous. Every master bricklayer must give twenty-four hours' notice to the Surveyor of the district, concerning the building to be altered or erected; but if the building is to be piled or planked, or begun with wood, it becomes the business of the carpenter to give such notice.

The footings of the walls are to have equal projections on each side; but where any adjoining building will not admit of such projections to be made on the side adjoining to such building, this direction to be complied with as nearly as possible.

The timbers in each rate, as girders, beams, trimming joists, &c. may have as much bearing as the nature of the wall will admit, provided four inches be left between the ends of such timber and the external surface of the wall.

External Walls.

Every front, side, or end wall, not being a party wall, is called an external wall.

External walls, and other external inclosures to the first, second, third, fourth, and fifth rates of buildings, must be of brick, stone, artificial stone, lead, copper, tin, slate, tile, or

iron; or of some or all of these materials in conjunction, except the planking, piling, &c. for the foundation, which may be of wood.

If any part to an external wall of the first and second rate is built wholly of stone, it is not to be less in thickness than as follows: first rate, fourteen inches below the ground floor, nine inches above the ground floor; second rate, nine inches above the ground floor.

Where a recess is meant to be made in an external wall, it must be arched over, in such a manner, that the arch and the back of such recess, shall respectively be of the thickness of one brick in length; hence no walls are allowed to be recessed which are not more than one brick in thickness.

No external wall to the first, second, third, and fourth rate, is ever to become a party-wall, unless the same shall be of the height and thickness above the footing, as is required for each party-wall to its respective rate.

Party Walls.

Buildings of the first, second, third, and fourth rate, which are not yet designed by the owner thereof to have separate and distinct side walls, on such parts as may be contiguous to other buildings, must have party walls; and they are to be placed half and half on the ground of each owner, or of each building respectively, and may be built thereon, without any notice being given to the owner of the other part, the first builder having a right so to do, when building against vacant ground.

Party-walls, chimneys, and chimney shafts hereafter to be built, must be of good sound brick or stone, or of sound bricks and stone together, and must be coped with stone, tile, or brick.

Party-walls, or additions thereto, must be carried up thirteen inches above the roof, measuring at right angles with the back of the rafter, and twelve inches above the gutter of the highest building which gables against it; but where the height of a party-wall so carried up, exceeds the height of the blocking course or parapet, it may be made less than one foot above the gutter, for the distance of two feet six inches from the front of the blocking course or parapet.

Where dormers (the term for windows in roofs, differing from sky-lights by their being vertical,) or other erections are fixed in any flat or roof, within four feet of any party-wall, such party-wall is to be carried up against such dormer, and must extend at least two feet wider, and to the full height of every such dormer or erection.

Provisions of the Builidng Act affecting the Bricklayer.

No recess is to be hereafter made in any party-wall of the first, second, third, and fourth rate, except for chimney flues, girders, &c. and for the ends of walls or piers, so as to reduce such wall in any part of it to a less thickness than is required by the act, for the highest rate of building to which such wall belongs.

No opening is to be made in any party-wall, except for communication from one stack of warehouses to another, and from one stable building to another, and the communications allowed must have wrought iron doors, and the pannels thereof are not to be less than a quarter of an inch thick, and must be fixed in stone door-cases and sills. But there may be openings for passages or ways on the ground, for foot passengers, cattle, or carriages, which must be arched over throughout with brick or stone, or brick and stone together, of the thickness of a brick and a half at the least, to the first and second rate, and one brick to the third and fourth rate. And if there is any cellar or vacuity under such passage, it is to be arched over throughout in the same manner as the passage over it.

No party-wall, or party-arch, or shaft of any chimney, new or old, must be cut into, except for the following purposes: if the fronts of buildings are in a line with each other, a recess may be cut, both in the fore and back front of such buildings, (as may be already erected,) for the purpose of inserting the end of such other external wall, which is to adjoin thereto. This recess must not be more than nine inches deep from the outward faces of such external walls, and not be cut beyond the centre of the party-wall. And for the purpose of inserting bressummers and story-posts, that are to be fixed on the ground floor, either in the front or back wall, the recess may be cut from the foundation of such new wall to the top of such bressummer, fourteen inches deep from the outward face of such wall, and four inches wide in the cellar story, and two inches wide on the ground story. The same may also be done for the purpose of tailing-in stone steps, or stone landings, as for bearers to wood stairs, or for laying-in stone corbels for the support of chimney jambs, girders, beams, purlines, binding or trimming joists, or other principal timbers.

Perpendicular recesses may also be cut in any party-wall, whose thickness is not less than thirteen inches, for the purpose of inserting walls and piers therein; but they must not be wider than fifteen inches, or more than four inches deep; and no such recess is to be nearer than ten feet to any other recess. All such cuttings or recesses must be immediately made good, and effectually pinned up, with brick, stone, slate, tile, shell, or iron, bedded in mortar.

No party-wall must be cut for any of the above purposes, if the same will injure, displace, or endanger the timbers, chimneys, flues, or internal finishings of the adjoining buildings.

The footing may be cut off on the side of any party-wall, where an independent side wall is intended to be built against such party-wall.

When any buildings (inns of court excepted) that are erected over gate-ways, or public passages, or have different rooms and floors, the property of different owners, are to be rebuilt, they must have a party-wall, with a party-arch or arches of the thickness of a brick and a half at the least, to the first and second rate, and of one brick to the third and fourth rate, between building and building, or between the different rooms and floors that are the property of different owners.

Inns of court are required only to have party-walls where any room or chamber communicates to each separate and distinct staircase, and which are also subject to the same regulations as respect other party-walls.

If buildings of different rates adjoin each other, and any addition is intended to be made to the lower rate, the party-wall of such building must be such as is required for that of the higher rate adjoining.

When any party-wall is raised, it is to be made of the same thickness as the wall in the story next below the roof of the highest building adjoining, but it must not be raised at all, unless it can be done with safety to such wall, and the building adjoining thereto.

Every dwelling-house built four stories high from the foundation, exclusive of rooms in the roof, must have its party-wall built according to the third rate, although such dwelling-house may be of the fourth rate. Every dwelling-house, also, exceeding four stories in height from the foundations, exclusive of the rooms in the roof, must have its party-wall built according to the first rate, although such house may not be of the first rate.

Chimneys.

No chimney is to be erected on timber, except on the piling, planking, &c. of the foundations of the building.

Chimneys may be built back to back in party-walls; but when this is done, they must not be less in thickness from the centre of such party-wall than as follows: first rate, or adjoining thereto, must be one brick thick in the cellar story, and half a brick in all the upper stories. Second, third, and fourth rate, or adjoining thereto, must be three-quarters of a brick in the cellar story; and half a brick in all the upper stories. Such

chimneys in party-walls of any of the four rates, as do not stand back to back, may be built as follows; from the external face of the party-wall to the inward face of the back of the chimney in the cellar story, one brick and a half thick, and in the upper stories, one brick thick from the hearth to twelve inches above the mantle. If such chimney is built against any other wall, the back may be half a brick thinner than above stated.

Those backs of chimneys which are not in party-walls of the second, third, and fourth rate, must be in every story one brick thick at least, from the hearth to twelve inches above the mantle. These backs may also be half a brick thinner, if such chimney be built against any other wall.

The breasts of chimneys, whether in party-walls or not, are not to be less than one brick thick in the cellar story, and half a brick thick in every other story.

All partitions between flues must not be less than half a brick thick.

Flues may be built opposite to each other in party-walls, but they must not approach nearer to the centre of such wall than two inches.

All chimney breasts next to the rooms, and chimney backs, and all flues, are to be rendered or pargeted.

Backs of chimneys, and flues in party-walls against vacant ground, must be lime whited, or marked in some durable manner, but must be rendered or pargeted as soon as any other building is erected to adjoin them.

No timber must be over the opening of any chimney for supporting the breast; but all chimneys must have a brick or stone arch, or iron bar or bars.

All chimneys must have slabs or foot paces of stone, marble, tile, or iron, at least eighteen inches broad, and at least one foot longer than the opening of the chimney when finished; and such slabs or foot paces must be laid on brick or stone trimmers at least eighteen inches broad from the face of the chimney breast, except there be no room or vacuity beneath, in which case they may be bedded on the ground.

Brick funnels must not be made on the outside of the first, second, third, or fourth rate, next to any street, square, court, road, or way, so as to extend beyond the general line of the buildings in such situations.

No metallic funnel or other pipe, for conveying smoke or steam, is allowed to be fixed near any public street, square, court, or way, to the first, second, third, or fourth rate, and no such pipe is to be fixed on the inside of any building nearer than fourteen inches to any timber, or other combustible material.

MECHANICS.

The science of Mechanics has been very concisely defined, the geometry of motion. It is divided by Sir Isaac Newton into the two branches of practical and rational mechanics. Practical mechanics treats of the six mechanical powers, of one or more of which every machine is composed; and rational mechanics comprehends the whole theory of motion, shews how to determine the motions produced by given powers or forces; and, conversely, when the phenomena of the motions are given, how to trace the powers or forces from which they arise.

Of Matter.

Every branch of natural philosophy acquaints us with some new properties of matter, the general nature of which, and those properties of it which respect mechanical science, it will here be requisite for the reader to consider.

The terms *matter, substance*, and *body*, though so nearly allied that they are occasionally employed in the same sense, without creating much confusion of ideas, have different significations, which ought to be understood.

Matter is the most general term of the three, and comprehends whatever is possessed of extension, and capable of making resistance, without regard to figure or quantity.

The word *substance* is compounded of the Latin preposition *sub* (under,) and the verb *stare* (to stand,) and approaches very nearly to the signification of the word matter, as it implies that which supports or stands under the different forms and appearances which are presented to our senses. Its meaning is, however, more restricted, and it is generally accompanied by the article, to denote a particular portion of matter.

The term *body* comes from the Saxon, and originally signified the person or form of a man, or other creature; hence it ought to be applied only to a substance possessing a definite form.

An examination of the general properties of matter will afford us a better idea of its nature, than can possibly be given by a definition. Some kinds of matter, as metals, wood, stone, &c. are visible, a property dependent upon their opacity, or power of reflecting to our eyes, some or all of the rays of light which

fall upon them. Other kinds of matter are invisible, on account of their perfect transparency, and their existence is ascertained only by their effects. Of this class are the various kinds of gases; for example, the atmosphere or air that we breathe, which, though totally invisible when dry and pure, yet is matter, as much as iron or the hardest body in nature.

Among the properties attributed to all matter, the following are too important to be passed over without particular notice, viz. SOLIDITY, EXTENSION, DIVISIBILITY, MOBILITY, INERTIA, ATTRACTION, and REPULSION.

The *solidity* of matter here meant is not opposed to fluidity, but expresses that property which every body possesses, of not permitting any other body to occupy the same place with it at the same time. This fact is an axiom in philosophy of the most incontestable kind. If a piece of wood or stone occupy a certain space, it must be removed before another body can be put into that space, and though the tyro may suggest that fluids do not oppose such resistance, it is only the facility with which they escape that induces the supposition of their being an exception to this universal property of matter. Under proper circumstances, their solidity is as obvious as that of the most solid substance: the piston of a syringe drawn full of water, cannot be thrust down if the aperture for the jet be stopped; and a pair of bellows filled with air, resists compression if the pipe be closed. The solidity of matter thus understood, is the same with what some writers call its impenetrability. These words, in common language, denote the property of not being easily separated into parts; a meaning very different from that attached to them in the sense just explained, and which should therefore be carefully remembered.*

Extension is another property of matter inseparable from its existence. The idea which we obtain of solidity by the resistance of bodies, and the impossibility of two bodies co-existing in the same identical place, immediately suggest and prove to us that matter is extended, or occupies a certain portion of space.

Divisibility is that property by which matter is capable of being separated into parts removeable from each other. We cannot conceive a particle of matter to be so small, as not to consist of two halves; this being the case, we are directly led to the conclusion that matter is capable of being divided to infinity. But, however natural this mode of reasoning appears, it has had many opponents, and those who suppose it just, have been considered as involving themselves in a cloud of palpable contradictions. To assume, it has been said, as a

first principle in philosophy, that matter is infinitely divisible, is to assert that it has no beginning of substance; that there are no limits between matter and nothing; and that a finite thing has infinite properties. Such being the difficulties attending the assumption of the infinite divisibility of matter, Sir Isaac Newton closes an admirable disquisition on the nature, laws, and constitution, of matter, by stating the great probability that God in the beginning formed matter into solid, massive, impenetrable, moveable particles or atoms, of such sizes and figures, and with such other properties, and in such proportion to space, as most conduced to the end for which he formed them; and that these primitive particles being absolute solids, are incomparably harder than any of the bodies compounded of them, even so hard as to be incapable of wearing or breaking in pieces, nothing but Infinite Power being able to destroy what Infinite Power made one in the first creation. That nature may be lasting, the changes of corporeal things are to be attributed only to the various separations and new associations of these permanent particles, and when compound bodies break, it is not in the midst of solid particles, but where these are laid together and touch only in a few points. By adopting this theory of ultimate atoms, we avoid the toils of metaphysics, although, at the same time, we take for granted what we cannot directly prove. But those propositions which are proved by the absurdity of supposing the contrary, are often as important; and nearly as well entitled to be received, as those which admit of strict demonstration; and although Sir Isaac Newton's conjecture respecting solid, indestructable atoms, has been buffeted among men of science for about one hundred years, it remains to be the prevalent opinion at this day; not because much new light has been thrown upon the subject, since the time of that justly renowned philosopher, but because it comports so well with the phenomena of nature, that an assent to it can scarcely be denied The extreme tenuity of certain substances to our general perception, is no proof against their being composed of particles perfectly solid; if a wet bladder be tied over the mouth of a pneumatic jar (that is, a jar open at the bottom,) and then gently dried, so as to remain well stretched, and the jar be then placed upon the air-pump, as soon as it is exhausted of air, the atmosphere pressing upon the exterior, will burst the bladder, and falling upon the pump-plate, will produce a loud report, like a gun. This effect could not be produced without the intervention of solid particles in air. Further, it seems impossible to account for the power of the most subtile agents of nature, if their ultimate atoms, however few they may be in a given compass, were not

equal in solidity to those which appear to us the hardest. Though the velocity of the electric fluid is immeasurably great, that velocity alone would be insufficient to produce its well-known effects on bodies of the closest texture, if it contained no principle of hardness within itself.

Having premised these considerations, we shall now take a view of parts actually separate, and if we shall find that these are so small and so numerous as to surpass imagination, we shall have approximated as nearly as the human understanding can do, to the attainment of an idea of the inconceivable minuteness of those solid, ultimate, indivisible atoms, which constitute matter. A pound of so gross a substance as cotton, may be spun into a thread exceeding one hundred miles in length; and the celebrated Boyle speaks of a thread of silk three hundred yards in length, which weighed no more than three grains and a half. But the ductility of gold is still more astonishing; a grain of gold can be hammered by the gold-beaters, until it will cover fifty square inches, and may be divided into two millions of visible parts, the gold which covers the silver wire used in making silver lace, is spread over a surface twelve times greater than in the last mentioned instance. In making this wire, a cylindrical bar of silver is strongly gilt, and afterwards converted into wire by drawing it successively through holes diminishing in magnitude, formed in plates of steel. By this means the surface is prodigiously augmented; but the wire still remains gilt, and preserves a uniform appearance, even when examined by the microscope. Sixteen ounces of gold, which would not occupy more space than one cubical inch and a quarter, will completely gild a wire sufficient to encompass the whole globe of the earth. The metallic particles in acid solutions are still more minutely divided. A single grain of copper dissolved in an ounce of diluted nitrous acid, will impart a green colour to a gallon of water, or cover one thousand square inches of bright iron with a coat of copper.

The odour of all bodies that excite the sensation of smell cannot be given out without a waste of their substance; yet this waste is so very small, that is, the fragrant parts of bodies are endued with such prodigious divisibility, as in general, for long periods, to occasion no perceptible diminution of the substance by which it is sustained. The odour of a grain of musk will continue for twenty years in an apartment where fresh air is admitted every day. Instances of the wonderful divisibility of matter are very abundant. Gunpowder, when exploded, expands to two hundred and forty-four times the bulk it occupied in a solid state; and water, when converted

into vapour or steam, fills a space eighteen hundred times greater than in its fluid form.

The wonders of the organized creation, as laid open to us by the microscope, are not less extraordinary than any thing we have yet contemplated, as exemplifying the divisibility of matter. Lewenhoeck discovered in the melt of a single codfish a greater number of animalculæ than there are inhabitants upon the face of the earth; and he calculates that one thousand millions of such animalculæ as are discovered in common water would not equal in magnitude a grain of common sand. Thousands of these minute beings might be contained on the point of a fine needle; yet, if we suppose them to be furnished with blood, like other animals, and if the globules of their blood bear the same proportion to their bulk as those of a man bear to his body, it may be proved that the smallest visible grain of sand would contain more of these globules than ten thousand of the largest mountains in the world would contain grains of sand. When we have well considered the minuteness of the smallest object in the microscopic world, and are apprized that innumerable particles of light must proceed to our eye from every part of that object, or it would not be visible, we may perhaps be led to institute an inquiry respecting the size of the particles of light itself. The result of such an investigation will mock our conception, even if nothing we have previously learned has had this effect. By a calculation apparently well conducted, a particle of light has been estimated at $\frac{1}{30,831,230,128,000}$ part of a grain.

From the preceding statement it is clear, that matter is actually divisible to a greater extent than we can conceive. On the other hand, it is next to an absolute certainty, that the hardest and most compact bodies are full of pores or interstices, their particles being either no-where in actual contact, or touching only in a few points. One proof of this is, that the hardest bodies are known to contract by cold, which contraction would be impossible, if their particles were incapable of a nearer approach to each other.

Mobility expresses the capacity of matter to be moved from one position or part of space to another.

Space is an abstract idea, and must be described principally by its want of properties. Its extension or capacity is without limits, and it does not consist of parts capable of actual separation from each other; the division of it therefore is always merely hypothetical. It is incapable of resisting in any degree the passage of bodies through it; and being per-

fectly uniform in all its parts, these cannot be distinguished from each other except by the bodies placed in them. When any given length, as a yard or a mile, has become familiar to us, we can reduplicate these measures as often as we please, without joining them to the idea of body, and we thus obtain our ideas of immensity.

Inertia is the term which designates the passiveness of matter, which, if at rest, will for ever remain in that state until compelled by some cause to move; and, on the contrary, if in motion, that motion will not cease, or abate, or change its direction, unless the body be resisted. That a body at rest will not move of itself, will be readily admitted; but its tendency to continue the motion once communicated to it, contradicting our ordinary experience, requires a little explanation. We can indeed produce no species of motion which will fully illustrate the proposition by experiment; but the conclusion seems undeniable, when we consider the effect produced by diminishing the obstructions to a body in motion. These obstructions are, gravitation, the resistance of the air, and friction. Gravitation, as will be understood when we come to treat of it, operates according to established laws, unsusceptible of change or modification by human art; most of the resistance of the air may be removed by means of the air-pump, but experiments with this machine can only be of small extent; the last-named obstruction to motion, viz. friction, is therefore the only one we have in general the power of diminishing; and yet in proportion as this one is diminished, we find the motion communicated to a body by a given impulse, so much increased that we cannot hesitate to consider the action of gravitation and the resistance of the air, combined with the friction yet undestroyed, as the sole causes of its ever ceasing. If a ball be projected along a rough pavement, it will soon stop; if projected on a level floor, the same force will send it much further; and on a surface perfectly plane, hard, and smooth, a ball also perfectly hard and smooth, as well as globular, would be carried perhaps five hundred yards, by the same force that would scarcely carry it twenty yards upon the rough pavement. So far, also, as reasoning confirms the explanation given of the inertia of matter, it seems as absurd to suppose that matter once put in motion can stop without a cause, as that when at rest it can move without a cause.

Attraction denotes the property which bodies have to approach each other. Philosophers enumerate five kinds of attraction, viz. the attraction of *cohesion*, of *gravitation*,

of *electricity*, of *magnetism*, and *chemical attraction*. Only the two first kinds of attraction belong to our present subject.

The attraction of *cohesion* takes place between bodies only when they are at very short distances from each other, and may be exemplified in a variety of ways. If two pieces of lead be scraped clean and smooth, and then strongly compressed, they will cohere almost as firmly as if united by solder. Planes of glass, marble, and other substances, exhibit similar phenomena. That this cohesion is not owing merely to the exclusion of the atmoshere, from the evenness of the surfaces employed, is proved by its taking place in vacuo.

The strength of the attraction of cohesion differing in different kinds of matter, is supposed to be the cause of the relative degrees of hardness in different bodies. It is therefore weakest in fluids; yet substances of this description indicate a disposition to unite. A fluid may be poured into a vessel till it rises above the brim, because the attraction between its particles resists, to a certain extent, its overflowing. From the same cause, the drops of dew upon the leaves of plants, and water thrown upon a dusty floor, where it is prevented from spreading, assume a globular form; small portions of quicksilver, also, when brought near each other, coalesce, and assume the same globular appearance.

A fluid contained in a vessel not full to the brim, assumes a concave form, being highest at the edge. If a plate of glass be immersed in water, the water immediately surrounding it will rise above the general surface. If a second plate of glass be immersed in the water, parallel to the former, and at a very short distance from it, the fluid will rise above its level between the two plates, and the nearer they are brought to each other, so as not to touch, the higher will the water rise. If the water be darkened, as by the addition of a little ink, and a glass tube with an excedingly small bore be placed perpendicularly in it, the rise may be distinctly detected to be very considerable. All effects of this description, to which may be referred the rising of water in a sponge, or other porous bodies, are usually attributed to what is called *capillary* attraction; but capillary attraction is only a particular modification or branch of the attraction of cohesion.

The attraction of *gravitation*, differs from the attraction of cohesion in this respect, that it is exerted at all distances, and by every particle of matter upon every other particle. This principle is the basis of the Newtonian philosophy. The planets and comets all gravitate towards the sun, and towards each other, as well as the sun towards them. The gravitating power of a body, is always proportionate to its

quantity of matter; and all the heavenly bodies are retained in their places by the due balance of their action on each other. An effect of gravity, or gravitation, familiar to all mankind, is the tendency of bodies to fall to the earth. This tendency is always towards a point, which is either accurately or very nearly in the centre of the earth; consequently bodies fall every-where perpendicularly to the surface, and on opposite sides of the globe, they fall in opposite directions or towards each other. It is not meant that there is any peculiar virtue or charm in the point called the centre; but because such is the result of the gravitation of bodies towards all parts of which the earth consists. The pressure of bodies to attain, in all cases, the lowest situation possible, or that nearest the centre of the earth, is what constitutes their weight. All substances having a certain degree of gravity; they have consequently all weight. Even smoke and vapours are possessed of it, the reason of their rising from the earth being the same as that which causes a piece of wood to swim in water, viz. they are lighter than an equal bulk of the atmosphere or fluid in which they are disengaged, and therefore their falling to the ground is as effectually resisted as the falling of a stone supported by the hand.

As the gravitating force is always proportionate to the quantity of matter, the most compact and the most loose, the greatest and the smallest bodies, descend through equal spaces in equal times, unless they fall through a resisting medium, which operates most upon those which have the greatest extension for their weight. If a guinea and a feather were dropt at the same instant from the top of a house, no one will be at a loss to say, which would soonest reach the ground; but in the exhausted receiver of an air-pump, these two bodies fall together. The guinea containing more solid matter than the feather, requires more force to put it in motion; but the attractive power being proportioned to the quantity of matter, its velocity is not greater than that of a body which requires less force to put it in motion. Another proof that the gravity of bodies is proportionate to their quantity of matter, is derived from experiments on the motion of pendulums. When the lengths of pendulums are equal, and they vibrate in equal arcs, they always acquire equal velocities at the corresponding points of those arcs, and their vibrations are consequently performed in times exactly equal, however different the bulk and texture of the material of which they are composed. The resistance of the air must be understood to be excluded in this experiment, because it acts unequally on different bodies, as already exemplified in the guinea and feather experiment.

In all places equally distant from the centre of the earth, the force of gravity is nearly equal. The earth is, however, not a perfect globe, but a little depressed on two opposite sides, partly like an orange. These depressed parts are at the poles, and the polar diameter of the earth has been found to be about thirty-four miles shorter than the equatorial one. The surface of the earth at the equator being therefore seventeen miles further from the centre than at the poles, the force of gravity there is less than at the poles. It is for this reason that a pendulum calculated to swing seconds in the polar regions, must be shortened before it will swing seconds at the equator; and that bodies at the equator loose $\frac{1}{250}$ part of the weight which they would have at the poles.

The power of gravity, at any given place, is greatest at the earth's surface, from whence it decreases both upwards and downwards, but not both ways in the same proportion. The force of gravity upwards decreases as the square of the distance from the centre increases; so that at a double distance from the centre above the surface, the force would only be one-fourth of what it is at the surface. The surface of the earth is, in round numbers, four thousand miles from the centre; if then a body at the surface weighs four pounds, and falls through sixteen feet in a second of time, it will at double this distance from the centre weigh but one pound, and will fall through but four feet in a second of time. Below the surface of the earth, the power of gravity diminishes in such a manner that its intensity is in the direct ratio of the distance from the centre, and not as the square of the distance; so that at the distance of two thousand miles, which is half a semi-diameter from the centre, the force would be but half what it is at the surface; at one-third of a semi-diameter, the force would be one-third, and the same ratio is applicable to all other distances. But although the force of gravity, strictly speaking, varies in the manner just stated, in receding from the surface, its operation at short distances is considered uniform, a quarter or even half a mile bearing so small a proportion to the earth's radius, that the difference is too insignificant to be noticed in calculations.

As the power of gravity appertains to every particle of matter, and the gravitating power of entire bodies consists of that of all their parts, under certain circumstances the gravity of a part of the earth somewhat counteracts that of the whole earth. Thus, the attraction of a lofty mountain is found to draw a plumb-line at the foot of it a little out of the perpendicular, so that in such a situation it does not tend to the centre of the earth.

The space which bodies actually fall through is sixteen feet and one-twelfth in the first second of time, in the latitude of London; and for other times either greater or less than that, the spaces descended from rest, are directly proportional to the squares of the times, while the falling body is not far from the earth's surface.

If two bodies, which contain equal quantities of matter, were placed at ever so great a distance from one another, and then left at liberty in space, and if there were no other bodies in the universe to affect them, they would fall equally swift towards one another, with a velocity continually accelerated, and would meet in a point which was at first exactly half way between them. But if two bodies, containing unequal quantities of matter, were placed at any distance, and left in the same manner at liberty, they would fall towards one another, with velocities which would be in an inverse proportion to their respective quantities of matter; moving as in the former case with an accelerated motion, they would meet in a point as much nearer to the place from which the heavier body began to fall, than to the place from which the lighter began to fall, as the quantity of matter in the former exceeded that in the latter.

That gravity should accelerate the descent of falling bodies; is an effect of its uniform action under all circumstances. Let us suppose that it causes a body to descend through the space of one mile in a minute; at the end of this time, the body will have acquired a velocity sufficient to carry it through two miles the next minute, although it received no new impulse from gravity; but as this accelerating cause remains, it adds another mile to its effect in the first minute, and therefore, at the expiration of two minutes, the body will have descended through four miles.

The spaces described by a uniformly accelerated motion, are always as the odd numbers, 1, 3, 5, 7, &c. and consequently the whole spaces are as the squares of the times, or of the last acquired velocities; for the continued addition of the odd numbers yields the squares of all numbers from unity upwards. Thus 1 is the first odd number, and 1 is the square of one; 3, the next number, added to 1, makes 4, which is the square of two; 5, added to four, makes 9, the square of 3, and so on. The *times* and *velocities* proceeding evenly and constantly, as 1, 2, 3, 4, &c. and the *spaces* described as 1, 3, 5, 7, &c. it follows that the spaces described

In 1 minute will be	1,	which is the	square of	1
In 2 minutes will be.......	1+3=4,	—	—	2
In 3 minutes will be....	1+3+5=9,	—	—	3
In 4 minutes will be	1+3+5+7=16,	—	—	4

Hence it is apparent that the spaces described in different times by a falling body, are to each other as the squares of the times from the beginning of the descent, or, which produces the same result, they are as the squares of the velocities acquired at the ends of those times.

The motion of a falling body being uniformly accelerated by gravity, the same cause uniformly retards the motion of a body thrown directly upwards. A body projected perpendicularly, with a velocity equal to that which it would have acquired by falling from any height, will ascend to the same height before it loses all its velocity.

Gravity and *weight,* it ought to be understood, are not interchangeable terms. Gravity is a power of which weight is the effect. Gravity has a constant tendency to impress, on every particle of bodies, a certain velocity, which would cause them to fall if they were not supported; weight is the resistance necessary to destroy this velocity, or produce this support.

When the many and wonderful discoveries which signalize the present age are considered, it seems presumptuous to mark the boundaries of success to human inquiry; but we may very safely assert, that no researches have ever yet been made, which enable us to discover, in the essential properties of matter, the cause of gravity. Of the existence of such a power, we are continually surrounded by the most indubitable proofs; and that its influence extends over and governs the solar system, and if the solar system, the whole material universe, there seems as little reason to deny. Sir Isaac Newton has conjectured that matter is composed of indivisible, perfectly solid particles or atoms, a theory that has been explained in the former part of this subject; but if the ultimate particles of matter be perfectly solid, they cannot be pervaded; if they be incapable of wearing or separation, they can throw nothing off; and if no single atom can receive or part with any thing, how can it act at all distances upon every other portion of matter in the universe? or how can any aggregation of atoms possess a power incompatible with the nature of its component parts? Such is a slight view of the argument on this subject; it is not our object to involve the reader in the mazes of useless theories, though we may, for his amusement, and the exercise of his judgment, occasionally glance at them and pass on. In various branches of knowledge, we discover abundant proofs that the effects we observe are produced by secondary causes, that is, these effects spring from the inherent properties, the properties originally impressed upon things by the Creator; but in the absence of the secondary cause of gravity,

or until we can prove it to be dependent upon the essential properties of matter, gravity should be considered as a term expressing merely a fact or phenomenon; and it is wise to refer the cause of it at once to the Final Cause of all things, and to regard it as the "Finger of GOD, the constant impression of Divine power."

Repulsion is the last property of matter which we have enumerated. A variety of considerations induce philosophers to admit that there is a sphere of repulsion which extends to a small distance round bodies, and prevents them from coming into actual contact with each other, except some force is exerted to overcome this resistance, and then the attraction of cohesion takes place. Dr. Knight defines repulsion to be that cause which makes bodies mutually endeavour to recede from each other, with different forces at different times; and that such a cause exists in nature, he thinks evident for the following reasons: 1. Because all bodies are electrical, or capable of being made so; and it is well known that electrical bodies both attract and repel. 2. Both attraction and repulsion are very conspicuous in all magnetical bodies. 3. Sir Isaac Newton has shewn from experiments, that the surfaces of two convex glasses repel each other. 4. The same great philosopher has explained the elasticity of the air by supposing its particles mutually to repel each other. 5. The particles of light are, in part at least, repelled from the surfaces of all bodies. 6. Lastly, it seems highly probable that the particles of light mutually repel each other as well as the particles of air. The Doctor ascribes the cause of repulsion, as well as that of attraction, to the immediate effect of the will of God; and as attraction and repulsion are contraries, and consequently cannot at the same time belong to the same substance, he supposes there are in nature two kinds of matter, one attracting, the other repelling; and that those particles of matter which repel each other, are subject to the general law of attraction in respect of other matter. A repellent matter being thus supposed equally dispersed through the whole universe, the Doctor refers to its operation a variety of natural phenomena; but whether, on his hypothesis, all the particular effects of repulsion can be accounted for, time and experience alone must determine.

In the instance which has already been adduced of the round drops of dew upon the leaves of plants, it is supposed not only that there exists an attractive force between the particles of the fluid, but a repulsive force between them and the leaf upon which they are suspended. That the drops are not in actual contact with the leaf, is evident from their rolling off in

a compact body with the greatest ease; as well as from their white or pearly appearance, which is an effect of the copious reflection of white light from the flattened part of the surface contiguous to the plant, and could not take place unless there was a real interval between the under side of the drop and the surface of the leaf. The power of repulsion will, in certain cases, cause metals to swim in fluids much lighter than themselves. A fine needle, if gently laid on the surface of water, will swim, and may be drawn off again by a magnet, without having in reality touched the fluid. In this instance, the needle is not heavy enough to overcome the power of repulsion between itself and the water, the attraction of cohesion cannot therefore operate, and though as much heavier than its own bulk of water as the largest piece of steel, it will float till pressed down by a greater force than its own weight. It would appear that, from the same cause, flies walk upon water, and oil refuses to mix with that fluid. Hence the feathers of water-fowl, which are covered with a thin coating of subtile oil, actually repel the surrounding water.

Of Motion.

No definition can be given of the term Motion which will satisfy the casuist. It expresses a simple idea, and cannot be explained by words more simple than itself. It has been called "a change of place," or the act by which a body corresponds with different parts of space at different times; but it would require great ingenuity to prove that these definitions amount to more than the assertion that "motion is motion." Perhaps that philosopher answered the question of "what is motion?" with as much perspicuity at least as any other, who began to walk, and observed to his inquirer that "that was motion."

It is by motion alone that we know the existence of bodies, and that a relation is established between them and our senses. Nothing can be produced or destroyed without motion, and every thing that happens depends upon it.

Space being nothing but an absolute and infinite void, the place of a body is that part of the immense void which it takes up or possesses; and this place may be considered absolutely or in itself, in which case it is called the absolute place of the body; or else with regard to the place of some other body, and then it is called the relative or apparent place of the body. As the place of a body may be considered absolutely or relatively, so may the motion of a body be distinguished in like manner. All motion is in itself absolute, or the change of absolute space; but when the motions of bodies are considered and compared

with each other, then are they usually denominated relative and apparent only: they are relative, as they are compared to each other; and they are apparent only, insomuch that not their true or absolute motion, but the sum or difference of the motions only is perceivable to us. Hence the absolute and relative motions of bodies may be different and even contrary.

If two ships set out and sail together in the same direction and with the same velocity, neither of them will appear to the other to move. Hence it is, that though the earth is continually revolving about its axis, and advancing in its orbit, yet, as all objects on its surface partake of the same common motion, they appear not to move at all, but are relatively at rest.

If two ships set sail at the same moment, in the same direction, but one of them sails only three miles while the other sails five miles an hour, the difference of their velocities, viz. two miles per hour, will alone be perceptible to a spectator in either of them, looking at the other.

But if two ships pass each other, the one will appear to the other to move with the sum of both velocities; so that in this case the apparent motion exceeds the true, as in the other instances it fell short of it. The reason of these phenomena of motion will be evident, if we consider that we must be absolutely at rest if we would discern at once the true or real motions of bodies about us. But as at absolute rest we can never be, from the motion of the earth, we must detect the real and absolute motions of bodies in general by means of observations made on their relative motions.

We are best acquainted with that kind of relative motion which consists in the transfer, from one place to another, of entire bodies, as the falling of a stone, or the flight of an arrow. But, besides this, there is another kind of relative motion, which, though not so obvious, is not less common or important. We allude to the motion of the parts of bodies among themselves, which though sometimes the object of our senses, yet, in other cases, we require the aid of reflection to be convinced of its existence. It is by this imperceptible motion that plants and animals grow, and by which the greatest number of the compositions and decompositions of the globe take place. We may form some idea of this, by observing the continual motion of the light particles which sometimes float about in water, when it is held in the rays of the sun; which proves that the parts of the water are in constant motion among themselves. But if we reflect a little, we shall discover that the particles of the most solid substances are also continually changing their situations. Heat expands and cold contracts the size of all bodies; and as we

know from experience, that the temperature of bodies is constantly varying, their particles must consequently be in continual agitation, in order to adapt themselves to the ever-changing size of the body. This is one of the causes of perpetual motion of the particles of matter; but there are no doubt an infinite number of other causes which escape our observation, and which we are perhaps incapable of discovering. The gradual changes that take place in all bodies during a series of years, sufficiently prove that they are constantly acting on each other; and from a view of all that we know on this subject, we are compelled to conclude that no particle of matter is in a state of absolute rest.

In considering motion, the several circumstances attending the communication of it from one body to another may be classed as follows:

1. The force which impresses the motion.
2. The quantity of matter in the moving body.
3. The velocity and direction of the motion.
4. The space passed over by the moving body.
5. The time employed in going over this space.
6. The force with which the moving body strikes another which is opposed to it.

In a mechanical sense, the inertia of every body causes it to resist all change of state. If at rest, it will not begin to move of itself; and if motion is communicated to it by another body, it will continue to move for ever uniformly, except it be stopped by an external agent. This has been shewn in treating of inertia. The causes by which bodies are put in motion, are called *motive powers*, of which the following are those generally used in mechanics: the action of men and other animals, wind, water, gravity, the pressure of the atmosphere, and the elasticity of fluids and other bodies.

The velocity of motion is estimated by the time employed in moving over a certain space, or by the space moved over in a certain time. The less the time, and the greater the space moved over, the greater of course is the velocity; and, conversely, the greater the time, and the less the space moved over, the less is the velocity. As no motion can be instantaneous, every body in motion must have a determinate velocity. To ascertain the degree of this swiftness or velocity, the space run over must be divided by the time. For example, suppose a body moves over 1000 yards in ten minutes, its velocity is 100 yards per minute, because 100 is the quotient of 1000 divided by 10. If we would compare the velocities of two bodies A and B, of which A moves 54 yards in 9 minutes, and B 96 yards in 6 minutes, the velocity of A will

be to that of B in the proportion of 6 to 16, because the quotient of 54 divided by 9, is 6; and the quotient of 96 divided by 6, is 16.

To know the space run over, the velocity must be multiplied by the time; for it is evident, that if either the velocity or the time be increased, the space run over will also be increased. If the velocity be doubled, then the body will move over twice the space in the same time; or if the time be twice as great, then the space will be doubled; but if the velocity and time be both doubled, then will the space be four times as great. Hence when two bodies move over unequal spaces in unequal times, their velocities are to each other as the quotients arising from dividing the spaces run over by the times. If two bodies move over unequal spaces in the same time, their velocities will be in proportion to the spaces passed over. Again, if two bodies move over equal spaces in unequal times, then their respective velocities will be inversely as the time employed; that is, if A in one minute, and B in two minutes, run over one hundred yards, the velocity of A will be to that of B as two to one.

A body in motion must every instant tend to some particular point. It may either always be to the same point, in which case the motion will be rectilinear; or it may be continually changing the point to which its motion is directed, and this will produce a curvilinear motion.

When a body is acted upon by one force, or by several forces in the same direction, its motion will be in the same direction as that in which the moving force acts; as the motion of a boat which a man draws to him with a rope. But if several powers differently directed, act upon a body at the same time, it will not exactly obey any of them, but will move in a direction somewhere between them. This subject may be rendered more plain by a diagram, and the illustration of it ought to be well considered by the young mechanic. Let a body A, fig. 1. pl. I. be impelled by a force acting on it in the direction AC. At the same instant, let it be impelled towards B, by another force that will carry it direct from A to B in the same time that the former force would carry it from A to C. Complete the parallelogram, ACBD, and draw the diagonal AD, and this line will represent the direction and distance the body will move in the same time when acted upon by both forces conjointly; for let us suppose a tube, equal to AB in length, in which a ball, A, can move freely; and that in the same time that the ball is moving uniformly from A to B, the tube is also moving uniformly from A to C, but so as to be always parallel to AB, and its extremities

describing the lines AC to BD. The ball has moved from A to B in the tube, in the same time that the tube has descended to CD, and therefore when the tube coincides with the line CD, the ball will be at the extremity, D, of that line, where it has arrived in the same time that it would have taken to describe either side. It is obvious also, that the ball thus subjected to the impulse of different forces, can have described no other line than the diagonal one; for by assuming smaller forces, and forming the parallelograms A *efg*, A *hik*, &c. it will be found at every interval, in the diagonal of the parallelogram. The motions along AB, AC, may be called the simple or constituent motions; the motion along AD is called the compound or resulting motion. Hence if we know the effect which the joint action of two forces have upon a body, and the force and direction of one of them, it is easy to find that of the other: for suppose AD to be the direction and force with which the body moves, and AB to be one of the impelling forces, then, by completing the parallelogram, the other power is found.

The practice of reducing compound forces to simple, and that of finding two or more forces equivalent to one, is called the composition and resolution of forces, the whole theory of which is comprised in and may be deduced from the following principle: two forces acting at the same time on a body, in directions which are oblique to each other, do not move the body by that part of their force, which, on acconnt of their obliquity, is opposite and contrary, but by what remains after the opposite forces are deducted.

Instances of motion produced by several powers acting at the same time are innumerable, and the application of this useful principle, by which they are governed, is therefore very extensive. A ship impelled by the wind and tide is one well known. A kite, acted upon by the wind and the string; the rain and snow that fall more or less obliquely according to the action of the wind; are other instances not less familiar. A fish, by striking the water with its tail, advances forward in a mean direction between the two impulses.—In jumping out of a carriage in motion, accidents frequently occur, and the adventurer falls short of the spot he aims at, for want of duly considering, or not knowing, that the lateral impulse he gives himself must, in a ratio proportionate to the swiftness of the carriage, be greater than if he sprung from a state of rest.

Motion is said to be *accelerated* if its velocity continually increases; and it is said to be *uniformly accelerated*, if its velocity increases equally in equal times.

Motion is said to be *retarded*, if its velocity continually *de*creases; and to be *uniformly retarded*, if its velocity *de*crease equally in equal times.

If a body be put in motion by a single impulse, and, moving uniformly, receive a new impulse in the same direction, its velocity will be augmented, and with that augmentation of velocity it will again proceed uniformly. But if at each instant of its motion it receives a new impulse, its velocity will be continually increasing; and if this impulse is always equal, and acts in equal times, the velocity will be uniformly accelerated.

On the contrary, if a certain velocity be given to a body, and it loses equal portions of that velocity, at each equal instant, by new impulses acting in a direction exactly opposite to its motion, it will be uniformly retarded.

The effect of gravitation in uniformly accelerating the descent of a body, and uniformly retarding one thrown directly upwards, has been shewn in the last section; but as a right notion of this doctrine is very important, in adverting to it again, we shall endeavour to exhibit it to the eye as well as the understanding. Let the perpendicular line AB, of the right-angled triangle ABC, fig. 2, pl. I. be considered as expressing the time which a body takes in falling, under the influence of gravity or any accelerating force, and the base line BC, as expressing the velocity acquired at the end of the fall. The time expressed by the line AB is divided into four equal parts or moments, A *r*, *r s*, *s t*, *t* B. The close parallel lines in the triangle A *r k*, repeated at equal intervals, and from the nature of the triangle, regularly increasing in length as they recede from the point A, denote equal accelerations of the velocity from the instant in which the body begins to fall. The line *r k*, therefore, will represent the velocity acquired by a falling body in the first moment of time; *s l*, the velocity acquired at the end of the second moment of time; *t o*, the velocity at the end of the third moment, and BC the velocity at the expiration of the fourth moment, or termination of the fall.

The body, during the second moment of time, if retaining only the velocity *r k*, which it had acquired at the end of the first, will describe the square surface *r k s m*; for this surface is generated by a continual repetition or motion of the line *r k*, during the time expressed by *r s*; as the area of the triangle A *r k*, is described by a uniformly increasing velocity during the time A *r*. But the area of the square is manifestly double the area of the triangle above it; whence it appears, that a body moving on, during the second moment, with the velocity

acquired at the end of the first, will fall twice as far in the second moment as in the first; and the rule deducible from this instance will universally hold, that is, the velocity acquired at the end of any given time, will carry the body twice as far in the same time. In pursuing the illustration of the figure, this will still further appear.

If the velocity continue to increase uniformly during the second moment, then the space will be as expressed by the area *r s l k*, and will be equal to three times the triangle A *r k*.

The *whole space* described by the body in the two first moments will be as the area A *s l*, which is four times greater than that of A *r k;* rendering it apparent that the space described by a body in its fall, is as the square of the time in which it falls; for here the time is 2, (because A *s* expresses two moments of the descent,) and the square of two is 4.

In the third moment, were the body to fall with the velocity *s l*, during the time *s t*, the space described will be as the rectangle under the time and velocity, that is, as the rectangular space *s l t n*, on which rectangle may be described four triangles, each equal to A *r k;* but as the velocity is still uniformly accelerated by the continued action of gravity, the space fallen through in the time *s t*, or third moment, will be as the area *s t o l*, or five times as great as A *r k*.

As the triangles A *r k*, A *s l*, A *t o*, ABC, are all similar; as A *s* is twice as much as A *r*, *s l* will be twice as much as *r k;* and as A *s* expresses the time, and *s l* the velocity, where the time is double the velocity is double. This rule applies to every part of the descent, and proves that the velocity is as the time.

If the spaces described in each moment be considered separately, the space in the first moment being 1, the space in the second moment, it will be obvious to inspection, is 3, in the third 5, in the fourth 7, the difference each time being 2.

The motion of a body ascending from B to A, and therefore uniformly retarded by the action of gravity, may be illustrated by the same figure, if we change only a few of the terms of explanation; thus BA will express the time which the body takes to rise to A, and any horizontal line compared with the base, as *t o*, *s l*, *r k*, will shew the velocity lost at the height at which it is drawn.

It is to be understood that the velocity above assigned to falling bodies, is that which they would acquire if they passed through a space where there was no air; but in fact the resistance of that fluid considerably diminishes the velocity acquired in falling, even when the body, from its density, is of a kind least affected by its action. A leaden bullet dropt from an

altitude of 272 feet, was found by Dr. Desaguliers to reach the ground in four seconds and a half; in which time, from theory, it should have descended through 325.6 feet, which makes a difference of about one-fifth of the actual descent between the experiment and the theory.

It has already been shewn, that if two forces act uniformly upon a body, they will cause it to move in a straight line; but if one of the forces is not uniform, but either accelerating or retarding, the moving body will describe a curve. A ball projected from a cannon would always proceed in a right line, if it were acted upon by no force except the impulse it received from the powder; but as soon as it leaves the mouth of the cannon, gravity acts upon it, and changes its direction. The ball, acted upon only by gravity and the original impulse, would describe a peculiar curve, called a parabola; but as the resistance of the air also contributes to the variation of the line described, and this resistance differs with the velocity of the ball, its path is not exactly determinable. In some cases, the resistance amounts to more than twenty times the weight of the ball; and when a ball moves with a velocity of two thousand feet per second, the amount of this resistance has been found to be one hundred times its weight. Hence the parabolic theory of projectiles is inapplicable to practice. Sir Isaac Newton has, indeed, shewn that the curve described by a projectile approaches more nearly to an hyperbola than a parabola; and that the resistance to the body is not proportional to the velocity itself, but to the square of the velocity. About two hundred years ago, philosophers took the line described by a body projected horizontally, such as a ball out of a gun, while the force of the powder greatly exceeded the weight of the bullet, to be a right line, after which they allowed it became a curve. Nicholas Tartaglia was the first who maintained that its path was a curve through the whole of its extent; but it was Galileo who determined the curve to be a parabola in a non-resisting medium.

The force with which a body moves, or which it would exert upon another body opposed to it, (force being constantly measured by its effects,) is always in proportion to its velocity multiplied by its weight or quantity of matter. This force is called the *momentum* of the body. If two equal bodies move with different velocities, their forces or momenta are as their velocities; and if two bodies move with the same velocity, their momenta are as their quantities of matter; therefore, in all cases, their momenta must be as the products of their quantities of matter and their velocities. This rule is the foundation of mechanics.

Laws of Motion.

A summary of the doctrine of motion has been reduced to three axioms, which are usually called the laws of motion, and are as follow:

I. All bodies are perfectly indifferent to motion and rest, that is, they are incapable when at rest of moving, and when in motion of stopping, without the action of an external cause.

II. The alteration of the state of any body, whether from rest to motion, or from one degree of motion to another, is always proportionate to the force which is impressed, and in the direction of that force.

III. Re-action is always equal to action; or, in other words, the actions of two bodies on each other are always equal, and exerted in opposite directions.

The proofs of the first and second of these laws have been shewn in the preceding sections, from which they are obviously deducible. The last is not so clearly implied; though as easily admitted to be true on a little consideration. That any body acting upon another loses as much force as it communicates, will be evident, if with a bullet suspended from a string we strike another bullet which is at rest, in which case the striking body will lose half its quantity of motion, and what it loses will be communicated to the other body. If the finger be pressed upon one scale of a balance, to counterpoise a weight in the other scale, the scale pressed by the finger acts against the finger with a force equal to that with which the other scale endeavours to descend. A great variety of facts might be adduced to the same purpose. If a man in a boat draws another boat to him, by means of a rope, the two boats will approach each other with equal quantities of motion. When a load is drawn by a horse, the load re-acts against the motion of the horse, and the progression of the animal is as much impeded by the load, as the motion of the load is promoted by the efforts of the horse; and suppose the animal to possess a force equal to one hundred, and the force necessary to keep the traces tight be equal to fifty, it will only be able to draw with the remaining force of fifty. When a cannon is discharged, the rarefied powder presses it backwards and the ball forwards with equal force, though the velocities are very different. If the ball weighs 10lbs. and the cannon and carriage 10,000lbs. the velocity of the ball will be a thousand times greater than that of the cannon, but the quantity of motion equal. The water by its re-action communicates to an oar as much motion as it receives, and therefore impels a boat: fishes swim and birds fly upon the same principle.

Of Central Forces.

All moving bodies endeavour to obtain a rectilinear motion, because it is the shortest and most simple; whenever, therefore, they move in a curve, there must be something that draws them from their rectilinear motion, consequently we may be certain they are acted upon by two powers at the least, and were the detaining power to cease, the moving body would instantly fly off in a straight line.

That force by which a body describing a curve endeavours to fly off in a straight line, is called the *centrifugal force;* and the opposite force, or that by which a body is every-where impelled, or in any manner tends towards some point as a centre, is called the *centripetal force.* If a bullet fastened to a string held in the hand be whirled round, and the string be broken or let loose, the bullet immediately flies off in a tangent to the circle it was previously describing; in this case, the string represents the *centripetal force,* and the power it has acquired to fly off, is the *centrifugal one.*

The centrifugal and centripetal forces are called together *central forces.*

Of the Centre of Gravity.

In every body, there is a certain point called the *centre of gravity*, the nature and properties of which require our attention, before we begin to treat of the mechanical powers.

The *centre of gravity* is that point in a body, about which all its parts exactly balance each other in every position.

If a body be suspended or supported by the centre of gravity, it will remain at rest in any position indifferently; and whatever supports this point bears the whole weight of the body, which, while so supported, cannot fall. The whole weight of a body may therefore be considered as centred in this point; and mathematicians, by the *place* of a body, often mean that point where the centre of gravity is situated. A body suspended by any other point, can rest only in two positions, viz. when the centre in question is either exactly above or below the point of suspension.

To balance a stick, which is of equal thickness throughout, across a finger, or any other narrow support, every child knows that he has only to find the middle of it; to balance one which is thicker at one end than the other, he knows that he must place the support nearer the extremity of the heavy end than the other, and that the difference of length on each side o. the balancing point must be proportionate to the difference

in the weight of the two ends. On the same principle, the common centre of gravity of two equal bodies, is just midway between them; but when the two bodies are unequal, it is nearer the greater body in proportion as it is heavier than the other; or the distances from the centre are inversely as the weights of the bodies. Let A, fig. 3, pl. I. be greater than B; join AB, upon which take the point C, so that CA : CB : : B : A, that is, if the weight of A be multiplied by the distance AC, and the product be the same as that of the weight of B multiplied by the distance BC, then C is the centre of gravity of the two bodies A and B. If the common centre of gravity of three bodies be required, first find C, the centre of gravity of A and B; and supposing a body to be placed there equal to the sum of A and B, find G, the common centre of gravity of it and D; then will G be the common centre of gravity of the three bodies A, B, and D. In a similar manner the centre of gravity of any number of bodies may be determined.

As gravity always acts in a direction perpendicular to the horizon, and as if the whole weight of a body were collected in the centre of gravity, this point always endeavours to descend in a vertical line, and with a force equal to the body's weight. Hence a vertical line passing through the body's centre of gravity, is called *the line of direction*. While the line of direction falls within the base upon which a body stands, the body cannot descend, but if it fall without the base, the body will fall. Thus the inclining body ABCD, fig. 4, pl. I. whose centre of gravity is E, stands firmly on its base CD, because the line of direction, EF, falls within the base. But if we attempt to set up a longer body, GHIK, fig. 5, with the same inclination, the centre of gravity L will be more elevated, and the line of direction LM falling without the base, it will drop the instant it is left to itself. The same effect would be produced by placing a sufficient weight on the top of the former body, fig. 4, for every such addition of weight would raise the centre of gravity, and therefore the weight would be sufficient to cause the fall of the body, the moment it was high enough to cause the line of direction to fall without the base, as shewn by fig. 5.

From the preceding observations, we may deduce the danger and absurdity of people's rising in a boat or other vehicle which is likely to be overset; for by that means they raise the centre of gravity, and a swing which would not have been attended with the least hazard while they were sitting, will then throw the line of direction beyond the base, and thus render their being overset inevitable. If, instead of

rising, the people had crouched as low as possible, many a boat's party would have saved themselves.

As the broader the base, and the nearer the line of direction is to the middle of it, the more firmly does the body stand; so, on the contrary, the narrower the base, and the nearer the line of direction is to the side of it, the more easily may the body be overthrown, because a less change of position is sufficient to remove the line of direction out of the base, and a less force is required to effect that change of position. It is for this reason that a sphere is so easily rolled upon a horizontal plane, and that it is so difficult to make any body stand upright on a point.

Various contrivances have been executed, taking their rise from the principle, that the centre of gravity always tends to the lowest place possible, as the manner of suspending the marine barometer, compasses, &c. An experiment frequently shewn by lecturers on natural philosophy, in illustration of the principle, is that made with a double cone, which appears to roll up two inclined planes, forming an angle with each other, and lying in the same plane. In this case, the double cone actually sinks as it advances, and by that means the centre of gravity keeps continually descending. It is necessary to this effect, that the height of the planes be less than the radius of the base of the cone. If the height be equal to the radius, the body will rest in any part of the plane; if the height be greater than the radius, it will descend. The two rules AB, CD, fig. 6, pl. I. are united by a hinge CA. The lower sides are straight; on the upper sides, one end is wider than the other, so that when opened they form two inclined planes. If a double cone EF, be placed near the hinge, it will roll towards the upper end of the planes, and thus apparently ascend; but in reality it is let down, because as the rules widen, the cone touches them in parts nearer and nearer the apex on each side.

When the line of direction of a body upon an inclined plane falls within the base, the body will slide down the plane; but it will roll down, if the friction of the surfaces be sufficient, when that line falls without the base. Thus the body C, fig. 7, will only slide down the inclined plane AB; but the body D will roll down the same surface. A sphere would descend upon an inclined plane without rolling, if there were no friction, which is the only cause of its rotation.

When a man is standing, the line of direction passes between his feet; when he walks, most of the motion is to preserve this line in the same position. The various methods and postures which we instinctively use to retain or to recover

that position of the line of direction which ensures our stability, might afford matter for curious reflection. We bend our body forward when we rise from a chair, or go up stairs; and in carrying a load, we always lean from it. Thus a man leans forward when he carries a burden on his back; backward, when he carries a burden on his breast; and to the right or left according to the situation of his load. The purpose of all these changes, is to make the line of direction fall between his feet.

If a body be suspended freely from different centres, its centre of gravity will be in the intersection formed by lines drawn from those centres perpendicular to the horizon. Hence we obtain an easy practical method of finding the centre of gravity of any irregular plane figure: suspend it by any point with the plane perpendicular to the horizon; from the point of suspension hang a plumb-line, and draw a line upon the body where the string passes over. Do the same for any other point of suspension, and where the two lines meet must be the centre of gravity. For example, supposing AB, fig. 8, pl. I. to be the body of which the centre of gravity is to be found. Suspend it in the first instance from any point, as D, so that it may move freely on that part: let a plumb-line hang from the pin on which it is suspended, and mark correctly the direction of the plumb-line on the body. Then suspend the body by another part, as F, and use the plumb-line as before. The line last drawn will intersect the first line DE in C, which is the centre of gravity.

Of the Mechanical Powers

The simple machines, of a combination of two or more of which all complex engines must consist, are called, by way of distinction, the *Mechanical Powers*. They are six in number, viz. the LEVER, the PULLEY, the WHEEL AND AXLE, the INCLINED PLANE, the WEDGE, and the SCREW. Some authors are of opinion that we ought only to reckon two simple machines, the *lever* and the *inclined plane;* for the pulley and the wheel and axle may be considered as compound levers, and the wedge and the screw are only modifications of the inclined plane; but as this enumeration is not in general use, and as it is in fact calculated rather to confuse than to simplify the subject, we shall pass it by.

If the abilities of man were limited by the extent of his natural strength, small indeed would be his knowledge of the works of nature, and few the refinements and comforts of civilized society. We can hardly look upon any production of art

which could have been obtained without the aid of mechanical contrivances. Hence we may conclude, that the construction of machines must have been long antecedent to a knowledge of the theory upon which their principles depend. The remains of Egyptian architecture exhibit the most surprising marks of mechanical genius. The stones laid upon the tops of the pyramids of Egypt, are each of them equal in size to a small house. The elevation of such immense and ponderous masses, to the tops of these and other stupendous fabrics, must have required an accumulation of mechanical power, which the architect of the present day cannot regard without astonishment.

In establishing the theory of the science of mechanics, some assumptions are made and taken for granted, though not strictly true, and when the theory has been explained, the proper allowances are made. The assumptions alluded to, are commonly called postulata, and are principally the four following:

1. That a small portion of the surface of the earth, although in reality convex, may be considered as a plane.

2. That heavy bodies descend in lines parallel to each other; for though all bodies tend towards the centre of the earth, yet the distance from which they fall is so inconsiderable, when compared with their distance from the centre of the earth, that their inclination is very trifling.

3. That the effort of any given power or weight, is the same in all points of its direction; or if a body be acted upon by any power in a given direction, the action will be the same, in whatever part of that direction it be applied.

4. That though all surfaces are more or less rough, and all machines imperfect, yet we must suppose all planes to be perfectly even; all surfaces quite smooth; all levers straight and inflexible, and without thickness and weight; all cords perfectly pliable, and all machines without friction and inertia.

Three things are always to be considered in treating of mechanical engines; a *weight* to be raised; the *power* by which it is to be raised; and the *instrument* or engine by which that power acts upon the weight.

The artifice in all mechanical contrivances is, to distribute the weight among such a number of agents, that the part sustained by the power may bear only a small proportion of the whole.

In calculating the power of a machine, it is usually considered in a state of equilibrium; that is, in the state when the power which has to overcome the resistance, just balances it. Having discovered how much power will be requisite for this purpose, it will then be necessary to add so much more as will

overcome the friction and weight of the machine itself, and give the necessary velocity.

Of the Lever.

The lever is of all machines the most simple; it is merely a bar of iron, of wood, or any solid material, by means of which a certain force, when one part of it rests against a fulcrum or prop, is capable of overcoming or resisting a greater force.

In the lever there are three circumstances to be particularly noticed: 1. The fulcrum or prop by which it is supported, or on which it turns as an axis or centre of motion. 2. The power to raise and support the weight. 3. The resistance or weight to be raised or sustained.

The points of suspension are those points where the weights really are, or from which they hang freely.

The power and the weight are always supposed to act at right angles to the lever, unless it be otherwise expressed.

The lever is distinguished into three sorts, according to the different situations of the fulcrum or prop, and the power, with respect to each other.

The lever is of the *first* order, when the fulcrum or prop is placed between the power and the weight.

The lever is of the *second* order, when the prop is at one end, the power at the other, and the weight between them.

The lever is of the *third* order, when the power is applied between the weight or resistance and the fulcrum.

The greater number of instruments in general use are levers of one kind or other. A poker, in stirring a fire, is a lever of the first order; the bar of the grate upon which it rests, is the fulcrum; the fire, the weight or resistance to be overcome; and the hand, is the power. Of this kind of lever, are constructed balances, steelyards, scissars, pincers, snuffers, &c. The instrument commonly called the iron-crow, by which large stones are loosened, and great weights raised to small heights, in order to get ropes under them, for raising them still higher, is also a lever of the first kind. AB, fig. 9. pl. I. represents this lever, in which C is the fulcrum, A the end at which the power is applied, and B the end where the weight acts. The parts AC and CB, on the right and left of the fulcrum, are called the arms of the lever. To find when an equilibrium will take place between the power and the weight, we must recur to what was formerly premised respecting the momenta of bodies, viz. that their momenta are always as the products

of their quantities of matter multiplied by their velocities; and therefore that the momentum of a small body will be equal to that of a large one, if its velocity, or the space it passes through, be such as to make their respective products equal. Now let us consider when this equilibrium will take place in the lever. Suppose the lever, AB, fig. 10. to be turned on its axis or fulcrum, so as to come into the situation DC; as the end D is at the greatest distance from the centre of motion, and as it has moved through the arch AD in the same time that the end B moved through the arch BC, it is evident that the velocity of the end A must have been greater than that of B, and for this reason it requires less weight or quantity of matter to produce an eqilibrium than B.

Let us now ascertain how much more weight B will require than A to balance. As the radii* of circles are in proportion to their circumferences, they are also proportionate to similar parts of them; therefore as the arches AD, CB are similar, that is, are both equal portions of the circles to which they respectively belong, the radius or arm DE, bears the same proportion to EC, that the arch AD bears to CB. But the arches AD and CB represent the velocities of the end of the lever, because they are the spaces which they moved over in the same time; therefore the arms DE and EC may also represent these velocities.

It is evident, then, that an equilibrium will take place, when the length of the arm AE multiplied into the power at A, shall equal EB multiplied into the weight at B; and, consequently, that the shorter EB is, the greater must be the weight at B to produce the balance; that is, the power and the weight must be to each other inversely as their distances from the fulcrum. Thus, supposing AE, the distance of the power from the fulcrum, to be twenty inches; and EB, the distance of the weight from the fulcrum, to be eight inches; and the weight to be raised at B to be five pounds; then the power to be applied at A must be two pounds; because the distance of the weight from the fulcrum, viz. eight, when multiplied into the weight five, makes forty; therefore twenty, the distance of the power from the prop, must be multiplied by two to get an equal product, which will produce an equilibrium.

It is obvious, that while the distance of the power from the prop exceeds that of the weight from the prop, a power less than the weight will raise it; so that then the lever affords a

* The radius of a circle is a line proceeding directly from the centre to the circumference.

mechanical advantage. But when the distance of the power is less than that of the weight from the prop, the power must be greater than the weight, or it will not raise the latter; when both the arms are equal, the power and the weight must be equal, to be in equilibrium.

The hammer lever differs in nothing but its form from a lever of the first kind. Suppose the handle of the hammer to be ten times the length of the iron part that draws the nail, then pulling backwards the handle, while the lower end rests upon the board as a fulcrum, the nail may be drawn with one-tenth part of the power which would be required to pull it out with pincers; because in using the pincers, the nail would move as fast as the hand, but in using the hammer the hand moves over ten times the space of the nail. A pair of scissars is composed of two levers of the first kind, the centre of motion being the rivet. If the hand or power be applied three times as far from the rivet as the material to be cut, each lever acting with a force of three, the scissars will act on the material six times more strongly than if the same power were applied directly to it.

The second kind of lever, that is, a lever employed so as to have the weight between the fulcrum and the power, is represented by fig. 11, pl. I.; A is the fulcrum, B the weight, and C the power. The advantage gained by this lever, as in the first, is as great as the distance of the power from the prop exceeds the distance of the weight from the prop. Thus if the point *a*, on which the power acts, be seven times as far from A as the point *b*, on which the weight acts, then one pound applied at C will raise seven pounds at B.

From the properties of this lever it is evident, that if two men carry a burden upon a stick between them, the shares of the weight which they bear, are to one another in the inverse proportion of their distances from it. The fact, indeed, is well known, that the nearer either of them is to the burden, the greater share he bears of it; and if one of them go directly under it, he bears the whole. If one man be at A and the other at *a*, with the pole or stick resting on their shoulders, and the burden B is placed five times as near the man at A, as it is to the man at *a*, the former will bear five times as much weight as the latter. Upon the same principle, two horses of unequal strength, may be yoked so that each horse may draw a part proportionable to his strength; for the beam they pull may be divided in such a manner, that the point of traction may be as much nearer to the stronger horse, as will be required to balance the different effects of their strength.

The oars and rudders of vessels are levers of the second kind;

the vessel is the weight or resistance, the water is the fulcrum, and the man who governs their motions is the power. A door is a lever of the second kind; the hinges are the centre of motion, the body of the door is the weight, and the hand by which it is moved is the power. A pair of bellows, nut-crackers, &c. are composed of two levers of the second kind.

In the third kind of lever, that is, when the power is between the weight and the prop, the power and the weight are in equilibrium, when the intensity of the power exceeds the intensity of the weight just as much as the distance of the weight from the prop exceeds the distance of the power. Thus, let E, fig. 12, be the prop of the lever EF, and W a weight of one pound, placed five times as far from the prop as the point at which the power P, acts, by the cord going over the fixed pulley D; in this case, the power must be equal to five pounds, in order to support the weight of one pound.

The third kind of lever is used as little as possible; on account of the disadvantage to the moving power; but it cannot always be avoided; an example of it is seen in rearing a tall ladder against a wall, where the power or strength of a man is exerted at a short distance from one end, and the task cannot be performed without more effort than would be necessary to bear the ladder.

The bones of a man's arm, and the limbs of animals generally, are levers of the third order; for when we lift a weight by the hand, the muscle that exerts its force to raise that weight, is fixed to the bone about one-tenth part as far below the elbow as the hand is, and the elbow being the centre round which the lower part of the arm turns, the muscle must therefore exert a force ten times as great as would be required simply for the suspension of the weight that is raised. The principle of vitality has an influence upon the strength of the muscles for which we are wholly unable to account; and a weight which would instantly break a muscle the moment it was dead, can be raised by that muscle while alive, without the smallest pain or difficulty. Vitality, therefore, being ordained to communicate so much energy to such flexible materials as flesh and blood, a lever of the third sort became most admirably adapted to the animal frame, because, if the power be sufficient, its operations are quick, and it is exerted or resides in a small compass.

In every species of lever there will be an equilibrium, when the power is to the weight as the distance of the weight from the fulcrum is to the distance of the power from the fulcrum.

In making experiments to prove the truth of the theory of the mechanical powers, as it is impossible to obtain materials

void of weight, the young mechanic ought to be apprized of the necessity of taking the only precaution in his power, that of perfectly balancing the levers, &c. before the weights and powers are applied, otherwise his results will not be satisfactory. Thus a lever made to exemplify the theory explained by fig. 9, pl. I. should from B to C be so much thicker than from C to A, that BC will balance CA when the fulcrum is at C. In like manner, for every other position of the fulcrum, the shorter arm of the lever should be made of the same weight as the longer.

If the weight to be raised be of considerable bulk, and if it be fixed either above or below the end of the lever, it will vary in its intensity according to the position of the lever. Let AB, fig. 13, represent a lever having a weight fixed above it, as A, of which the centre of gravity is *a*, and the line of direction *a b*; then *a b* is the point in the lever upon which the weight acts; but if the lever is moved into the position CD, the line of direction of the weight will fall nearer to the fulcrum of the lever, and consequently act with less force upon it; but if the lever is placed in the direction EF, the line of direction will fall further from the fulcrum, and therefore its action on the lever will be increased. On the contrary, opposite effects will take place when the weight is below the lever, as represented by fig. 14.

When the weight is suspended from the lever by a rope, or any flexible material, no alteration, as exemplified by fig. 13, can take place, because the point of suspension or point of action is not altered. When, therefore, two draymen carry a barrel on a coulstaff, to which it is suspended by a chain, the point on which the weight acts not being altered by inclining the staff in going up or down hill, each man will sustain the same weight as if on level ground. But if they carry the barrel upon two dogs, then the weight does not swing, and the centre of gravity is below the lever; therefore the point on which the weight acts, will, by inclining the lever, be made to approach the highest end; and the first man, in going down hill, by having this point removed from him, will be eased in part of his burden, and the last man will have his equally increased.

If several levers be combined together, so that a weight appended to the first lever, may be supported by a power applied to the last, as in fig. 15, pl. I. where three levers of the first kind are so disposed that a power applied to the point L of the lever C, may sustain a weight at the point S of the lever A, the power must be to the weight, in a ratio, or proportion compounded of the several ratios which those powers

that can sustain the weight by the help of each lever, when used singly and apart from the rest, have to the weight. For instance, if the power which can sustain the weight W by the help of the lever A, be to the weight as 1 to 5; and if the power which can sustain the same weight by the lever B alone, be to the weight as 1 to 4; and if the power which could sustain the same weight by the lever C, be to the weight as 1 to 5; then the power which will sustain them by the help of the three levers joined together, will be to the weight in a proportion consisting of the several proportions multiplied together, of 1 to 5, 1 to 4, and 1 to 5; that is, as $5\times4\times5$, or of 1 to 100. For since, in the lever A, a power equal to one-fifth of the weight W, pressing down the lever at L, is sufficient to balance the weight; and since it is the same thing whether that power be applied to the lever A at L, or the lever B at S, the point S bearing on the point L, a power equal to one-fifth of the weight W, being applied to the point S of the lever B, will support the weight; but one-fourth of the same power being applied to the point L of the lever B, and pushing the same upward, will as effectually depress the point S of the same lever, as if the whole power were applied at S; consequently a power equal to one-fourth of one-fifth, that is, one-twentieth of the weight W, being applied to the point L of the lever B, and pushing up the same, will support the weight. In like manner, it matters not whether that force be applied to the point L of the lever B, or to the point S of the lever C; since if S be raised, L, which rests on it, must also be raised; but one-fifth of the power applied at the point L of the lever C, and pressing it downwards, will as effectually raise the point S of the same lever, as if the whole power were applied at S, and pushed that lever up; consequently a power equal to one-fifth of one-twentieth, that is, one-hundredth part of the weight W, being applied to the point L of the lever C, will balance the weight at the point S of the lever A. This method of combining levers is frequently used in machines and instruments, and is of great service, either in obtaining a greater power, or applying it with more convenience.

Of the Balance.

The common balance, the extensive utility of which, in comparing the weights of bodies, is so well known, consists of a lever of the first kind, the arms of which are equal in length. The points, therefore, from which the weights are suspended,

being equally distant from the centre of motion, will move with equal velocity, consequently, if equal weights be applied, their momenta will be equal, and the balance remain in equilibrium.

In order to have a balance as perfect as possible, it is necessary to attend to the following circumstances:

1. The arms of the beam ought to be exactly equal both as to weight and length, and should at the same time be as long as possible, relatively to their thickness, and the weight they are intended to support; because the further the points of suspension are from the centre of motion, the more the momentum of the weights is increased, and the more sensible will be the instrument.

2. The points from which the scales are suspended, should be in a right line, passing through the centre of gravity of the beam; for by this means the weights will act directly against each other, and no part of either will be lost, on account of any oblique direction.

3. If the fulcrum, or axis of motion, passes through the centre of gravity of the beam, and if the fulcrum and the points of suspension be in the same right line, the balance will have no tendency to one position more than another; but will rest in any position it may be placed in, whether the scales be on or off, empty or loaded, provided the weight in each scale be the same. The equality of two weights suspended from a beam, where the centres of gravity and of motion are thus coincident, being shewn by their quiescence, and not by any particular position, such a beam is evidently inapplicable to common use, for which but one position ought to denote the equality of the weights; and for that one, the horizontal position is the most convenient.

If the centre of gravity of the beam, when level, be immediately *above* the fulcrum, it will overset with the smallest action; that is, the end which is the lowest will descend and not rise again, and it will descend thus with more swiftness, the higher the centre of gravity, and the less the points of suspension are loaded. Hence such a beam will make equal weights appear unequal. If the centre of gravity of the beam be *below* the fulcrum, the beam will not rest in any position but when level; but if disturbed from that position, and then left at liberty, it will vibrate, and at last come to rest on the level. In a balance, therefore, the fulcrum ought always to be placed a little above the centre of gravity. Its vibrations will be quicker, and its horizontal tendency stronger, the lower the centre of gravity, and the less the weight upon the points of suspension.

The balance.

4. The friction of the beam upon the axis ought to be as little as possible; because, should the friction be considerable, the force required to overcome it will much injure the sensibility of the instrument; upon which account, though one weight should a little exceed the other, the greater will not preponderate, if the excess be insufficient to overcome the friction and bear down the beam. The axis of motion should be formed with an edge like a knife, and made very hard. These edges, in small balances, are at first made sharp, and then rounded upon a fine hone, or piece of buff leather, covered with some impalpable cutting powder. This operation causes a sufficient bluntness or rolling edge. The excellence of the instrument depends in a great measure upon the regular form of this rounded part. The scales should be hung upon an edge of the same kind.

5. The pivots, which form the axis of motion, should be in a straight line, and at right angles to the beam.

6. The rings, or pieces on which the axis bears, should be very hard and well polished, parallel to each other, and of an oval figure, that the axis may keep its proper bearing, or always remain at the lowest point

7. The beam should always be made so strong, as to be inflexible by the greatest weight it is likely to sustain; as if it bend it will be rendered less sensible, and as the arms will probably bend unequally, the balance will cease to give a correct result. That the beam may not be thick or clumsy without utility, it should be strongest at the middle, from which part to the points of suspension it should be gradually diminished in thickness, because the strain upon it is likewise so diminished. In small balances, the beam is mostly round, but in large ones it is generally rectangular, its transverse section being a parallelogram, of which the long sides are vertical. A square, a round, or any other form, would require a greater quantity of metal to possess the same strength.

8. Very delicate balances are not only useful in nice experiments, but are likewise much more expeditious than others in common weighing. If a pair of scales, with a certain load, be barely sensible to one-tenth of a grain, it will require a considerable time to ascertain the weight to that degree of accuracy, because the turn, being very small, must be observed several times over. But if no greater accuracy were required, and a balance were used which would turn with the one-hundredth part of a grain, a tenth of a grain more or less would make so great a difference in the turn that it would be seen immediately.

9. A curious effect caused by exciting a tremulous motion in the beam, deserves to be noted. If a balance be found to turn with a certain addition, and is not moved with any smaller weight, a greater sensibility may be given to that balance by drawing a file, a saw, or any similar instrument, along any part of the beam or its support; for the jar produced by this operation will diminish the friction on the moving parts so much, that the turn will be evident with one-third or one-fourth of the addition that would else have been required. In this way, a beam which would hardly turn with the addition of one-tenth of a grain, will turn with one-thirtieth or fortieth of a grain.

10. When the arms of a balance are unequal, the balance is said to be *false*, because it does not give the true weight of the body, whether it be suspended from the shorter arm or the longer one. There are, however, several properties of the false balance, which are extremely useful in the estimation of weights, as well as in correcting errors which may have arisen in the adjustment of the true balance.

A balance with unequal arms will weigh as accurately as another of the same workmanship, provided the standard weight be first counterpoised, then taken out of the scale, and the thing to be weighed be put into the scale, and adjusted against the counterpoise. Or when proportional quantities only are considered, as in chemical and other philosophical experiments, the bodies and products under examination may be weighed against the weights, taking care always to put the weights into the same scale; for then, though the bodies may not be equal to the weights, yet their proportions among each other will be the same as if they had been accurately so.

A weight which counterpoises an ounce when suspended from the longer arm of a false balance, being added to the weight which counterpoises an ounce suspended from the shorter arm, will always be greater than two ounces. The excess is that part of an ounce which is expressed by a fraction, of which the numerator is the square of the difference of the arms, and the denominator the product of the arms. If any substance be successively weighed from the longer and shorter arms of a false balance, the true weight will be a geometrical mean between the false weights.

11. But though the equality of the arms may not always be essential, yet it is indispensably necessary that their relative lengths, whatever they may be, should continue invariable. For this purpose, it is requisite, either that the three edges be all truly parallel, or that the points of suspension and support

should be always in the same part of the edge. The last point is the most easily obtained.

The index of a balance is that slender rod rising perpendicularly from the middle of the beam, of which it shews the inclination from the horizontal position. A sliding weight is sometimes fitted upon the index, in order to raise or depress the centre of gravity of the balance. This contrivance is useful in adjusting the best distance between the centre of gravity and the fulcrum.

The lever, we have observed, is of all machines the most simple; the balance is merely a lever, yet, in applying it to practice, it appears, from the preceding considerations, that many difficulties are to be encountered before it becomes fitted to afford any thing like accurate results. The workman finds it a severe check upon him, to keep the arms equal, while he is making the other adjustments, and this point, though certainly not the easiest to manage, is but one of many in which he ought perfectly to succeed. If then the adjustment of a simple lever be so difficult a matter, the sources of imperfection in complex machines may well be supposed to be very considerable. Yet when we regard what has been actually executed, we find no reason to conclude that the ingenuity of man is too limited for his happiness; or that most of the obstacles which, at present baffling us, form the desiderata of human knowledge, will not in time be removed. In this place, it may gratify the reader to notice the neat approximation to perfection which has been shewn in the construction of the balance.

Muschenbroek mentions his being possessed of a balance which turned with one-fortieth of a grain. The substances he weighed were between 200 and 300 grains. The balance therefore weighed to $\frac{1}{12000}$ part of the whole.

Two accurate balances of Bolton's are mentioned in the Philosophical Transactions, vol. 66. One of them, it is said, would weigh a pound, and turn with one-tenth of a grain. This, supposing the pound to be avoirdupoise, is $\frac{1}{70000}$ of the weight, and shews that the balance could be depended on to four places of decimals, and probably to five. The other balance was adapted to weigh half an ounce or under, and turned with $\frac{1}{200}$ of a grain, which is about $\frac{1}{22000}$ of the weight.

In the same volume of the Philosophical Transactions, two other balances, one of them Read's, and the other Whitehurst's, are noted. Read's, when loaded with 55 pounds, readily turned with one pennyweight; but very distinctly turned with four grains when tried more patiently. This being about $\frac{1}{90000}$

part of the weight, the balance may be well depended on to five places of figures.—Whitehurst's balance weighs one pennyweight, and is sensibly affected with $\frac{1}{2000}$ of a grain, which is $\frac{1}{48000}$ part of the weight.

W. Nicholson, so well known as the intelligent author of many scientific works, observes, that he has a balance made expressly for him by a skilful artist in London. With 1200 grains in each scale, it turns with one-seventieth of a grain. This is $\frac{1}{84000}$ of the whole; and therefore about this weight may be known to five places of figures. The proportional delicacy is less in greater weights. The beam will weigh nearly one pound troy, and when the scales are empty, it is affected by $\frac{1}{1000}$ of a grain. On the whole, it may be usefully applied to determine all weights between 100 and 4000 grains to four places of figures.

A balance in the possession of Dr. George Fordyce, is mentioned in the Philosophical Transactions, vol. 75. It was made by Ramsden, and turns upon points instead of edges. With a load of four or five ounces, a difference of one division in the index was made by $\frac{1}{1000}$ of a grain. This is $\frac{1}{384000}$ part of the weight, and consequently this beam will ascertain such weights to five places of figures, besides an estimate figure.

The Royal Society's balance, which was also made by Ramsden, turns on steel edges, upon planes of polished chrystal. Nicholson, who speaks of it in his Chemical Dictionary, says he was assured, that it ascertained a weight to the seven-millionth part. He was not present at this trial, which must have required great care and patience, as the points of suspension could not have moved over much more than one-fiftieth of an inch in the first half minute: but from some trials which he saw, he considered it probable, that it might be used in general practice to determine weights to five places and better.

Tables of specific gravities, are sometimes carried to five, six, and even seven places of decimals; but from the preceding account of balances it is obvious, that experience does not authorise the practice; and that deductions founded on such a supposed accuracy in weighing, are of a very questionable nature. In general, where weights are given to five places of figures, the last figure is hypothetical; and where they are carried further, we have reason to doubt the veracity or competence of the experimentist.

Of the Steel-yard.

The statera, or Roman steel-yard, is a lever of the first kind, and is used for finding the weights of different bodies, by one single weight, placed at different distances from the prop or

centre of motion U, fig. 16, pl. I. The shorter arm UM, is of such a weight as exactly to counterpoise the longer arm UN. If the longer arm be divided into as many equal parts as it will contain, each equal to UO, the single weight Q (which we may suppose to be one pound) will serve for any thing as heavy as itself, or as many times heavier as there are divisions in the arm UN equal to the distance UO; or any quantity between its own weight and that quantity. For example, if Q be one pound, and be placed at the first division 1, in the arm UN, it will balance one pound in a scale or on a hook at P; if it be removed to the second division at 2, it will balance two pounds at P; if to the third, three pounds, and so on to the end of the arm UN. If these integral divisions be subdivided into as many equal parts as a pound contains ounces, and the weight Q be placed at any of these subdivisions, so as to counterpoise the goods in the scale, the pounds and odd ounces of those goods will by that means be ascertained.

In the Danish and Swedish steel-yard, the body to be weighed, and the constant weight, are fixed at the extremities of the steel-yard, but the point of suspension or centre of motion, moves along the lever till the equilibrium takes place. The centre of motion therefore shews the weight of the body.

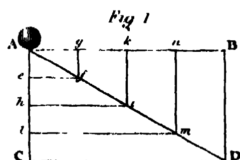
Of the Pulley.

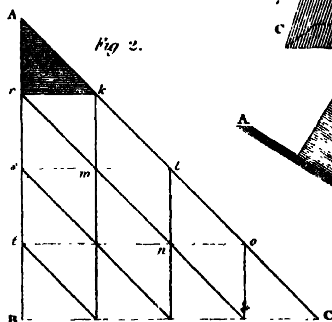
The pulley is a small wheel turning on an axis, with a drawing rope passing over it. The circumference of the pulley is generally hollowed to receive the rope, which is attached on the one hand to the moving power, and on the other to the resisting force.

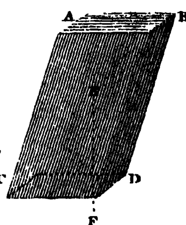
The pulley is usually called a *sheave*, and is so fixed in a frame or block, as to be moveable on a pin passing through its centre. When pulleys are made of wood, a ring of iron or brass is generally let into the middle of them, to work upon the pin, as they would otherwise wear unequally, and their motion would then be impeded by an increased degree of friction.

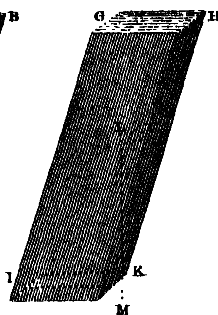
A *fixed* pulley is one which has no motion except upon its axis; a *moveable* pulley is one which rises and falls with the weight. The expression "moveable pulley" is clear enough, but the epithet *fixed* being rather calculated to exclude the idea of motion entirely, the expression "fixed pulley," requires more particular notice from those to whom the subject is new.

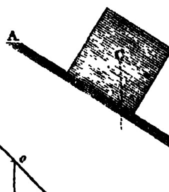
The *gorge* or *groove* of a pulley, is the hollow part of the circumference which receives the rope or cord; it is frequently hol-

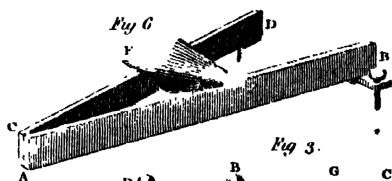


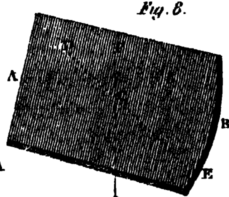


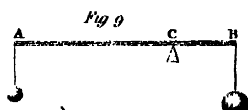


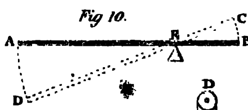


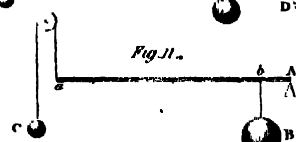


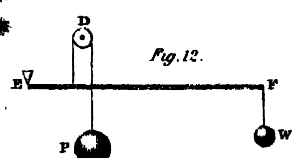


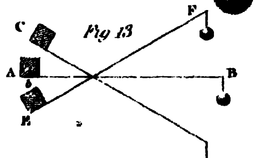


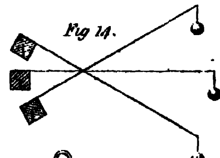


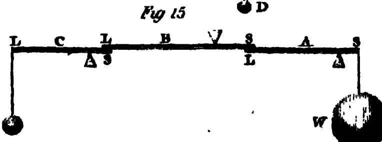


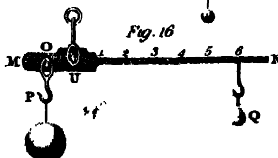












J Smith del. S. Porter sc.

Published by Henry Fisher, Caxton, London,

lowed out angularly, so that the rope is, by the pressure, so wedged in the angle, that it cannot glide or slip in its motion.

A pair of blocks, with the rope fastened round it, is commonly called a *tackle*.

Two equal weights attached to the ends of a rope going over a fixed pulley, as fig. 1, pl. II. will balance each other, for they stretch the rope equally, and if either of them be pulled down through any given space, the other will rise through an equal space in the same time, and consequently as their velocities are equal, they must balance each other. This kind of pulley, therefore, gives no mechanical advantage, but the use of it is a source of great convenience. It serves to change the direction of draught; it gives a man an opportunity of applying his weight instead of his muscular strength, but not of lifting more than his weight; it also enables a man to raise a weight to any point, without moving from the place he is in, whereas he would otherwise have been obliged to ascend with the weight; and, lastly, by it several men may apply their strength to the weight by means of the rope, with as much facility, under the same circumstances, as one person only.

In treating of the lever, it might have been observed, that the prop may be regarded as a third power, which keeps in equilibrium the motive force and the resistance, or which concurs with the one, to enable it to sustain the effort of the other. If the lever of the second order, AB, fig. 3, have its fulcrum at B, the weight in the middle at C, and the power at A, half the weight being supported by the fulcrum, a power equal to the other half will keep it in equilibrium. This will apply to the illustration of the action of pulleys, which, when the weight is appended to the circumference, may be considered as levers of the first kind, and when the weight is appended to the centre, they may be considered as levers of the second kind: hence the ropes *a b*, fig. 1, hanging at equal distances from the centre, *c*, (which must be regarded as the fulcrum,) equal weights must be in equilibrium, exactly as they would be if placed in the scales of a common balance. But if one weight be further from the centre or fulcrum than the other, they will balance each other only as they would in a steelyard, and, therefore, though still a lever of the first kind, a less weight will suspend a greater. Thus, if the pulley, as in fig. 2, have different gorges, and the weight R of six ounces, be hung at the distance of one inch from the fulcrum, *c*, and the weight S of three ounces be hung at the distance of two inches from the same centre; the two weights R and S, though in the proportion of 2 to 1, will balance each other.

If the weight S were only two ounces, it would produce the same effect upon R, provided its distance from the fulcrum were proportioned to the diminution of its weight; that is, if it were three times as far from the centre *c*, as R.

We have now to shew that the moveable pulley acts like a lever of the second order. Let the moveable pulley A, fig. 4, pl. II, be fixed to the weight W, with which it rises and falls. In comparing it with the lever alluded to, the fulcrum must be considered as at F; the weight acts upon the centre *c*, by means of the neck *ch;* the power is applied at D; and the line DF will represent the lever. The power, therefore, as in fig. 3, is twice as far from the fulcrum as the weight, and the effect in both cases is alike, viz. the proportion between the power and the weight, in order to balance each other, must be as 1 to 2. It is evident, therefore, that the use of this pulley doubles the power, and that it will enable a man to raise twice as much as by his strength alone. Or, as variety in illustration will sometimes catch the attention, and familiarize a subject to some whose ideas of it would not otherwise be distinct, the action of this pulley may be viewed in a light somewhat different from the above. Every moveable pulley may be considered as hanging by two ropes equally stretched, and which must consequently bear equal parts of the weight; the rope FG being made fast at G, half the weight is sustained by it, and the other part of the rope, to which the power is applied, has only the other half of the weight to support; consequently the advantage gained is as 2 to 1.

When, as in fig. 5, the upper and fixed block, or pulley-frame, contains two pulleys, which only turn upon their axes, and the lower moveable block contains also two, which not only turn on their axes, but rise with the weight W, the advantage gained is as 4 to 1; for each lower pulley will be acted upon by an equal part of the weight; and because each pulley that moves with the weight, diminishes one-half the power necessary to keep the weight in equilibrium, the power by which W may be sustained will be equal to half the weight divided by the number of lower pulleys; that is, as twice the number of the lower or moveable pulleys is to 1, so is the weight suspended to the power. But if the extremity A, fig. 6, be fixed to the lower block, it will sustain half as much as a pulley; consequently here the rule will be, as twice the number of moveable pulleys, adding unity, is to 1, so is the weight to the power. To prevent the ropes *a* and *b* from rubbing against each other, the upper fixed pulley may have a double gorge. The pulley *d* belongs not to the

system of pulleys, it is merely used in the plate, to separate from the ropes, and shew more distinctly the power, P.

If instead of one rope going round all the moveable pulleys, the rope belonging to each of them be made fast at the top, as in fig. 7, a different proportion between the power and the weight will take place. Here it is evident, that each moveable pulley doubles the power; thus, if there are two moveable pulleys, the power will sustain four times its own force or weight; if three pulleys, eight times its own weight; if four pulleys, sixteen times its own weight. In the figure where three moveable pulleys are shewn, the weight W, of sixteen ounces, is supported by the power P, of two ounces. This arrangement of pulleys takes up much room, raises the weight very slowly, and is not convenient to fit up. It is therefore seldom used, notwithstanding the great power gained.

These rules are applicable, whatever may be the number of pulleys employed.

The large space occupied by pulleys, when arranged under each other, as in fig. 5 and 6, is an inconvenience that would often render them useless, and such an arrangement would increase the liability to entanglement, particularly on shipboard; it is therefore common to place all the pulleys in each block on the same pin, by the side of each other, as in fig. 8. The advantage, and the rule for the power, are the same here as in fig. 5. In this kind of tackle, the ropes are not exactly parallel, a direction which should be preserved as much as possible; but the defect is not very considerable.

The reason of the parallel direction of the ropes being better than an oblique one, is that less power is required to sustain the same weight; and in proportion to the obliquity of the ropes must be the increase of the power. When there are many pulleys in the same block, and the end of the rope to which the power is applied terminates over one of the outside pulleys, that pulley always endeavours to get into a line with the centre of suspension or middle of the moveable pulleys, from which the weight hangs. In consequence of this, the friction of the pulleys against the sides of the block is so great as sometimes to equal the power. Hence the multiplication of pulleys thus used, soon ceases to be advantageous; they are seldom effective, if their number exceeds three or four. Smeaton, the eminent engineer, was the first who disencumbered himself of the difficulty here stated, by making the rope terminate over the middle pulley or sheave in the fixed block, which is thereby kept perpendicularly under the other, and the friction of the sheaves is on their centres of motion only. The

number of sheaves must always be uneven, or this improvement cannot be adopted.

To avoid as much as possible the friction and shaking motion of a combination of pulleys, James White, a very able mechanic, invented and obtained a patent for the concentric pulley, fig. 9. M and N are two of these pulleys, one of them being fixed, the other moveable. They are usually made of brass, and answer the purpose of as many distinct pulleys as there are grooves. In this case, as in fig. 5, the weight being divided among the number of ropes, a power of 1 will support a weight of 12.

In speaking simply of a system of pulleys, the common arrangement of them is meant, viz. that where the number of ropes is just twice the number of the moveable pnlleys. Fig. 4, 5, and 8, are all systems of this kind. The ropes are spoken of as if they were in different lengths, but it can hardly require an observation, that the expression is used merely because it is convenient, and that there is in fact but one rope, the parts of which are alluded to as if they were separate.

It has been shewn, in illustrating fig. 2. pl. II, that by means of a pulley of several grooves, the actions of two unequal powers may be made to balance each other. In like manner, a constant equilibrium or relation may be preserved between two powers, the relative forces of which continually change. Watchmakers derive great advantage from the application of this principle to their work. The spring of a watch always acts with the greatest power immediately after it has been wound up, and its power is continually but gradually diminishing, till the watch stops. If this inequality of the maintaining power operated upon the wheels, the watch would not go two successive hours at the same rate; but the effects of it are completely avoided by the peculiar conformation of the pulley off which the spring draws the chain. Instead of many concentric gorges upon the fusee, they make only one, but that one is in a spiral form upon a truncated cone, see fig. 10. When the watch is wound up, the chain extends from the upper or narrowest part *e*, to the spring-box. The spring is then at the strongest; but it acts on a part so near the centre of motion, or axis F G, that its power on the wheels is the same as just before it stops, when its absolute strength is much diminished; and its weakness is favoured by pulling at a longer lever, or at a greater distance from the centre of motion, that is, at *f*. Now as the alteration in the power of the spring from its greatest to its least strength is gradual, so is the extension of the lever, or

increase of the distance from the centre of motion, FG, also gradual between the extremes *e f*; therefore the spring and the fusee may be so adjusted to each other, that the power operating upon the wheels will always be the same.

We have postponed till now one remark which the reader has probably anticipated, viz. that it is convenience alone, and not any actual increase of power, which we gain by machines; for in all contrivances by which power is gained, a proportional loss of time is suffered. This is evident from a consideration of the properties of the lever; and is still more evident, if possible, in considering the action of pulleys. If one man, by means of a tackle, can raise as much weight as ten men could by their unassisted strength, he will be ten times as long in performing his task. Suppose a man at the top of a house draws up ten weights, one at a time, by a single rope, in ten minutes, let him have a tackle of five moveable pulleys, and he will draw up the whole ten at once with the same ease as he before raised up one; but in ten times the time, that is, in ten minutes. Thus we see the same work is performed in the same time, whether the tackle be used or not; but the convenience is, that if the whole of the ten weights were in one mass, they may be raised with the tackle, though it would be impossible to move them by the unassisted strength of one man.

Or suppose, instead of ten weights, a man draws ten buckets of water from the hold of a ship in ten minutes, and that the ship being leaky, admits an equal quantity in the same time. It is proposed, that by means of a tackle he shall raise a bucket ten times as capacious with the same exertion of strength. With this assistance, he draws up the large bucket, but in as long a time as he employed to draw up the ten, and therefore he is as far from gaining on the water in the latter case as in the former.

The remark, that whatever is gained in power is lost in time, would be perfectly correct, even if machines were destitute of friction and of inertia, but as these hinderances are always present, the truth is, as we shall afterwards see, that power, instead of being increased by the use of machines, is actually diminished. The convenience, however, which is obtained by a well constructed machine, is an ample recompense for the actual loss of power.

Of the Wheel and Axle.

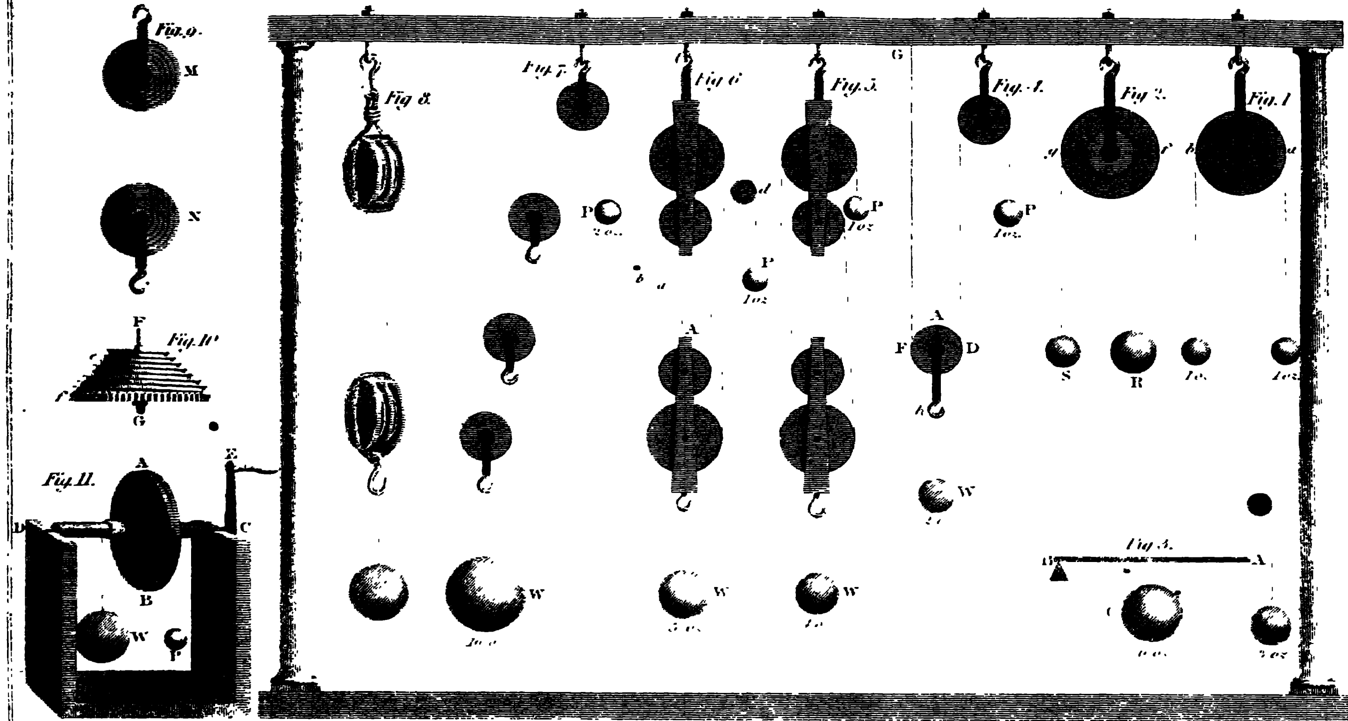
The wheel and axle, sometimes called the *axis in peritrochio*, is a machine of the most extensive utility, and, to suit different purposes, is greatly diversified in form. It is nearly allied to

the pulley; the same illustrations will frequently serve for them both; and, like the pulley, it may be considered as an assemblage of levers, or a perpetual lever, because from its constant renewal of the points of suspension or resistance, it frees us from the great defect of the simple lever, which can only be used to raise weights to small elevations.

This mechanical power consists generally of a wheel with an axis fixed to it, so as to turn round with it; the power being applied at the circumference of the wheel, the weight to be raised is fastened to a rope which coils round the axis. But a machine which has in reality no wheel, comes under the denomination of the wheel and axle; such is a windlass, where an axle is turned by a winch or handle: here the handle is virtually the wheel, its revolution renders it a perpetual lever, its power is the same as that of a wheel whose circumference is equal to the circumference of the circle the handle describes, and therefore the machine is identified with the wheel and axle.

AB, fig. 11, is a wheel, and CD an axle fixed to and moving round with it. If the rope which goes round the wheel be pulled, and the wheel be turned once round, it is evident that so much rope will be drawn off as would encompass the wheel; but while the wheel turns once round, the axle turns once round, and consequently the rope by which the weight is suspended will wind once round the axle, and the weight will be raised through a space equal to the circumference of the axle. Hence the velocity of the power will be to that of the weight, as the circumference of the wheel is to the circumference of the axle. This being the case, the weight and the power will be in equilibrium, when the one is to the other as the circumference of the wheel is to the circumference of the axle.

Mathematicians demonstrate, that the circumferences of different circles bear the same proportion to each other as their respective diameters; consequently, the power and the weight will balance each other, when the power bears the same proportion to the weight that the *diameter* of the axis bears to the *diameter* of the wheel. Thus, let fig. 2, pl. II, which in a preceding page was considered as a pulley of two concentric grooves, be now considered as a wheel and axle; *d e* representing the diameter of the axle, which we will suppose to be one inch; and *f g* the diameter of the wheel, which we will suppose to be six inches; then *one* ounce acting as the power, S, will balance a weight or resistance of *six* ounces acting as a weight, R. In whatever form the machine presents itself, this proportion between the power and the weight will subsist, when the power is applied to the circumference of the wheel, or to a winch, as at


Fig. 1
Fig. 2
Fig. 3
Fig. 4
Fig. 5
Fig. 6
Fig. 7
Fig. 8
Fig. 9
Fig. 10
Fig. 11
M
N
P
W
S
R
1 oz
2 oz
3 oz
6 oz
10 oz

E, fig. 11, and the weight to the axle. Therefore if W be 100 lbs. and the power, P, or a force acting at E, be equal to 10lbs. supposing the diameter of the wheel, or the diameter of the circle described by the winch, to be ten times greater than the diameter of the axle, they will be in equilibrium, and a small additional force will cause the wheel to turn with its axle, and raise the weight, and for every inch which the weight rises, the power will fall ten inches

When the wheel and axle are considered as a perpetual lever, the fulcrum is the centre of the axle, the longer arm is the radius of the wheel, and the shorter arm the radius of the axle. From this again it is evident that the longer the wheel, and the smaller the axle, the stronger is the power of the machine; but then, as in other instances, the drawback on the power gained is the time lost, which is always proportionate to the disparity between them.

A capstan is an axle or cylinder of wood, with holes in it, in which levers are inserted, to turn it round; these are like the spokes of a wheel without the rim.

In some cases, the weight is not connected with the axle by a rope, but is immediately affixed to the axle itself. A bell, which is moved in ringing by a wheel and axle, is an example of this: here, in once turning the bell round, the velocity of the bell is as the circumference described by its centre of gravity.

On the other hand, in what is called the circular crane, the power is not applied to the wheel by means of a rope, nor does it act upon any handle or spokes, but by a man walking within the wheel; as the man steps forward, the part upon which he treads becomes the heaviest part of the wheel, and descends till it is the lowest. Thus he keeps going on, and by treading upon every part of the wheel's circumference in its turn, the revolution is effected. This mechanical contrivance is unwieldy, from the necessity of employing a large wheel, and its power insignificant, because the man can ascend so little from the bottom of the wheel. It is also unsafe for the man, for if the rope suspending the weight give way, or his feet slip, he is exposed to the greatest danger.

In considering the theory of the wheel and axle, the rope is supposed to have no sensible thickness; but if the rope is thick, or if there is several folds of it round the axle, in obtaining the radius of the axle, the measurement must be made to the middle of the outside rope; for it is plain, that the distance of the weight is as effectually increased by the coiling of the rope as by any other means.

If teeth are cut in the circumference of a wheel, and if

they work in the teeth of another wheel of the same size, as fig. 1, pl. III, it is evident that both the wheels will revolve in the same time; and the weight appended to the axle of the wheel B, will be raised in the same time as if the axle had been fixed to the wheel A. But if the teeth of the second wheel be made to work in teeth made in the axle of the first, as fig. 2, every part of the circumference of the wheel D, is applied successively to the circumference of the axle E, of the first wheel C; and as E is much less than D, it is evident that it must go round as many times oftener than D, as the circum ference of D exceeds its own circumference; or, which amounts to the same thing, if the number of teeth in the axle E, be divided by the number of teeth in the wheel D, the product will shew the number of revolutions which E will make for one revolution of D. In order to obtain a balance here, between the power P, and the weight W, the power must be to the weight, as the product of the circumferences or radii of the two axles multiplied together, is to the circumferences or radii of the two wheels. This will become sufficiently clear, if the whole be considered as a compound lever, the explanation of which, as given in its proper place, will shew that fig. 2, requires the same proportion between the weight and the power, and therefore is represented by the compound lever, fig. 3. The dotted lines shew those halves of the wheels and axle, of which the different parts of the lever are equal to the radii.

Instead of a combination of two wheels, three or four, or any number of wheels, may work in each other, and by thus increasing the number of wheels, or by proportioning the wheels to the axles, any degree of power may be acquired. By increasing the length of the axle, by varying the sizes of the wheels, and placing their teeth sometimes on the circumference, and sometimes on the side of the rim, the action of the power may be transmitted to a distance, the direction of the movement changed, and any given velocity assigned to particular parts.

What we have uniformly called the *teeth* of wheels, are not in all cases distinguished by that name, though they always are so when the work is small, as clockwork, and generally when the wheels are made of metal, whatever be the size of the work; but in large works, where the wheels are of wood, and the teeth are separate pieces mortised into the rim, they are called *cogs*.

It may also be observed, that we have called the small wheel E, fig. 2, pl. III, an axle, because in point of reasoning as to the effect, it is the same thing whether it is really a

toothed axle, or a wheel of that size upon a small axle. For the sake of distinction, the small wheel E is called by mechanics a *pinion*, and sometimes a *nut*. Its teeth are also called *leaves*. In large machines, *trundles* are frequently substituted for pinions or nuts, being of easier manufacture, and performing the same office. These trundles are cylinders or spindles, parallel to each other, and placed circularly in two plain pieces of wood at the top and bottom. The teeth of the wheel then catch the spindles of the trundle, as they would do the teeth of a nut or pinion.

That useful machine, the crane, so much employed in raising or lowering goods, is indebted for its value principally to the wheel and axle. Cranes are very variously constructed, but the object in all of them is to manage a great weight with an inconsiderable power. An elevation of a crane, the general construction of which is now becoming very prevalent in London, is shewn in fig. 4, pl. III. It is approved, from its requiring no very expensive frame-work, and because it can be turned all round. AB is a stout beam, turning in a cast-iron collar at B, affixed to the beams in the floor of the wharf; it goes down about twelve feet below this, and has a steel pivot at the lower end, which works in a brass socket or collar, so that the beam AB can turn freely round without shaking. CD are the two beams of the jib, with a fixed pulley at E, over which the chain for hoisting the goods works. The other end of this chain winds round the axle *c*, of the great wheel F, of 98 teeth; this wheel works in a pinion of seven leaves, on the same axle with the wheel G of 35 teeth. The wheel G, works in a pinion, H, of 14 teeth. When a great power is required, the winch handle is applied to a square on the end of the axis or spindle of this pinion; but for a less weight, the winch is put on the axle of the wheel G. In this case, to lessen the friction, the pinion may be disengaged, or, as it is usually called, thrown out of gear, by sliding its axle lengthways. For this purpose, it must be provided with two grooves, and must have a clip or catch to fall into one of these in either of its situations. The frame containing the wheels is formed by two cast-iron crosses, bolted to the main beam, AB, by their vertical arms, of which IK are the two in front.

Machines of this description should be furnished with a ratchet wheel, as *m*, with a catch to fall into its teeth. This wheel will at any time support the weight, and keep it from descending, if the person who turns the handle should, through inadvertence or carelessness, quit his hold while the weight is suspended. This very easy mode of preventing the danger

which would result from the running down of the weight, if left at liberty, should never be omitted.

Of the Inclined Plane.

The inclined plane is any flat surface which forms an angle less than a right angle, with the plane of the horizon. When hogsheads, or pipes of wine, &c. are to be let down into a cellar, or brought up out of it, a plank is laid along the stairs, and thus forms an inclined plane.

The time which a rolling body takes to descend upon an inclined plane, is to the time in which it would descend vertically by its absolute gravity, in free space, from the highest part of the plane, in the ratio or proportion which the length of the plane bears to its perpendicular height. The whole theory of the inclined plane rests upon this principle.

Suppose the plane AB, fig. 5, pl. III, to be parallel to the horizon, the cylinder, C, will remain at rest on whatever part of the plane it is laid. If the plane be placed perpendicularly, as AB, fig. 6, the plane will contribute nothing to the support of the cylinder, C, which will therefore descend with its whole force of gravity, or require a power equal to its whole weight to keep it from descending. But suppose AB, fig. 7, to be a plane parallel to the horizon, and AD a plane inclined to it; if the whole length AD be three times as great as the perpendicular DB, the cylinder C will be supported upon the plane, or kept from rolling down, by a power equal to a third part of the weight of the cylinder; it is clear, therefore, that a weight may be rolled up this inclined plane by a third part of the power which would be required to draw it up by the side of an upright plane, as AB, fig. 6, where the force required must be equal to its whole weight; but it is to be noticed, that upon the inclined plane the weight goes over three times the space; which proves that, as in all other cases, we only substitute time for power.

As the horizontal plane, fig. 5, supports the whole weight of the cylinder, C, and the vertical plane, fig. 6, or plane perpendicular to the horizon, supports none of it; so, in all cases, the less the angle of elevation, or the gentler the ascent is, the greater will be the weight which a given power can draw up; for the steeper the inclined plane, the less does it support of the weight, and of course the greater the tendency the weight has to roll.

The weight is always most easily either drawn or pushed in a line *g r*, parallel to the plane, and passing through the centre of the weight; for if one end of the line be fixed at *g*, and the other end inclined towards D, the cylinder C would be drawn

against the plane, and the power must be increased in proportion to the greater difficulty of the line of traction; also if the line be carried above *r*, the power must be increased, but in that case only in proportion as it endeavours to lift the body off the plane. In stating the power necessary to support the cylinder C, on the inclined plane AD, the parallel direction of the line of traction, as it is the most favourable one, is taken for granted.

In estimating the draught of a waggon or other vehicle up-hill, the draught on the level must be added. Suppose the hill rises one foot in four, then one-fourth part of the weight must be added to the draught on level ground. If the weight were 12 cwt. and its draught on the level was $1\frac{1}{2}$ cwt. then one-fourth of 12 cwt. or 3 cwt. added to $1\frac{1}{2}$ cwt. would give $4\frac{1}{2}$ cwt. for the real draught necessary to draw 12 cwt. up a hill rising one foot in four. Hence may be discerned the great disadvantage of hilly roads, and the propriety of loosing a little time in winding about hills where it is possible, rather than exhaust the power of the horses in passing over them.

Of the Wedge.

The fifth mechanical power or simple machine, is the wedge, which is a piece of wood, metal, or any firm material, thin at one end and thick at the other. The thin end is called the point or edge, and the thick end is called the head or base of the wedge.

The action of the wedge resembles most that of the inclined plane, but the theory of it is by no means complete. The wedge, when driven, as it mostly is, by percussion, for example, by the blow of a hammer, produces an effect differing considerably from that of pressure, so as not to admit of exact calculation. A weight of five hundred pounds, pressing on the back of a wedge, will often make very little impression upon a body, which a hammer weighing only two pounds, if, when the force of the blow is extinguished, it have acquired a velocity rendering its momentum equal to five hundred pounds, would instantly sever. This great difference of effect between percussion and pressure, when the momenta are equal, is perhaps owing to the tremulous motion or vibration produced by percussion among the parts of the body, which, when so agitated, and the wedge has once entered, has the friction between its sides and that of the wedge lessened, as well as the cohesion of its parts diminished. Until therefore we are thoroughly acquainted with the nature and force of the tenacity of bodies, and the activity with which they vibrate under a

given impulse, (and these are branches of knowledge to which philosophers are as yet nearly strangers,) the theory of the wedge will not be susceptible of much precision. We are not, however, wholly in the dark, and the following mode of regarding the subject is generally approved.

AB, fig. 8, pl. III, is a wedge driven into the cleft CDE, of the wood FG. When the wood does not cleave at any distance before the wedge, there will be an equilibrium between the power impelling the wedge downward, and the resistance of the wood acting against the two sides of the wedge, when the power is to the resistance as half the thickness of the wedge at its back, that is, from A to B, is to the length of one of its sides; because the resistance then acts perpendicularly to the sides of the wedge.

When the wood cleaves at some distance before the wedge, which is generally the case, the power impelling the wedge will not be to the resistance of the wood as the thickness of the back of the wedge is to the length of both its sides, but as half the thickness or length of the back is to the length of either side of the cleft, estimated from the top or acting part of the wedge. The reason of this is, that if we suppose the wedge to be lengthened, so as to reach the bottom of the cleft at D, the same proportion will hold; namely, the power will be to the resistance as half the length of the back of the wedge is to the length of either of its sides; or, which amounts to the same thing, as the whole length of the back is to the length of both the sides.

The thinner a wedge is at the back, that is, the more acute the angle of its longitudinal section, the more powerful is its action, or the greater the effects which may be produced by the same force.

When this instrument is employed to cleave a hard body, the parts of which strongly adhere together, its advantage is augmented in proportion as the wedge is sunk or driven deeper between these parts. For example, if the piece of wood, FG, have three bandages, *r*, *s*, *t*, all of equal strength, and which may represent the strength with which the parts of the wood cohere, the wedge may be considered as acting by the arms DE, DC, of two angular levers. If then the force of the wedge, exceeds a little that of the first bandage *r*, this bandage will be severed. The second bandage, *s*, though as strong as the first, will be more easily broken by the action of the same wedge, because the arms of the lever by which it then acts are lengthened by the quantity *r s*; and the increased facility with which the last bandage will be broken, will, in like manner, be proportionate to the in-

creased length of the arms of the lever formed by the sides of the cleft.

The wedge is a mechanical power of singular efficacy, and the percussion by which its action is obtained, is precisely that force which we can, with the greatest convenience, almost indefinitely increase. By means of the wedge, the walls of houses may be propped, rocks split, and the heaviest ships raised up; —operations to which the lever, the wheel and axle, and the pulley, are either ill-adapted, or entirely incompetent.

To the wedge are referred the axe, the spade, chisels, needles, knives, punches, and, in short, all instruments which, beginning with edges or points, grow gradually thicker. A saw is a number of chisels fixed in a line; and a knife, if its edge be examined with a microscope, will be found to be only a fine saw.

Of the Screw.

The sixth and last mechanical power which we have to notice, is the screw.

The screw, strictly speaking, consists of two parts, which work within each other. One of these parts, and which is always meant when the word screw is used alone, is a *solid* cylinder, on the circumference of which is cut a spiral groove; it is, as we have formerly observed, when specifically named, called an *outside* or *convex* screw. The other part, is a *hollow* cylinder, or, at least, whatever its external form may be, it contains a cylindrical hole, within which is cut a spiral groove corresponding to that of the convex screw, which can be turned within it, and the spiral projections of the one lock into the spiral hollows of the other. For the sake of necessary contradistinction, this latter part is called an *inside*, a *concave*, or *socket* screw, when spoken of generally, without reference to any other use than its principal one, of an indispensable companion to the convex screw; but when it consists of a small piece of metal, as for drawing tight bolts of any description, it is most commonly called a *nut;* and when it is of considerable size, as for a large press or vice, it is usually called a *box*.

The *thread* of a screw is its spiral projection; the *pace* or *step* of a screw is the *distance* between the threads; and the groove or gorge is the *hollow* between the threads.

To obtain an idea of the nature of the screw, and of its affinity to the inclined plane, cut a piece of paper in the form of an inclined plane, or half wedge, as LMN, fig. 9, pl. III, and then wrap it round a cylinder, fig. 10; the edge of this plane or paper, LMN, will form a spiral round the cylinder,

which will give the thread of the screw. The height of the plane is the pace of the screw, or distance of one thread from another; its base is the circumference of the screw, and its length is estimated by this circumstance and the height of the pace.

A screw is seldom used without the application of a lever to assist in turning it; it then becomes a compound machine of great force, either in compressing the parts of bodies together, or in raising great weights. As the lever or winch must turn the cylinder once round, before the weight or resistance can be moved from one spiral winding to another, or before the screw working in its box can rise or sink the distance between the threads as from *a* to *b*, therefore as much as the circumference of the circle described by the lever is greater than the pace of the screw, or distance between the threads, so much does the force of the screw exceed the motive force. For example, suppose the pace or distance of the threads to be half an inch, and the length of the lever 12 inches, the circle described by the extremity of the lever where the power acts, will be about 76 inches, or 152 half inches, consequently 152 times as great as the distance between two contiguous threads; therefore, if the intensity of the power at the end of the lever, be equal to one pound, that single pound will balance 152 pounds acting against the screw. If as much additional force be exerted as is sufficient to overcome the friction, the 152 pounds may be raised; and the velocity of the power will be to the velocity of the weight as 152 to 1. Hence we may clearly perceive, that the longer the lever, and the nearer the threads to one another, so much the greater is the force of the screw.

The friction of the screw is very great, but we are indebted to this circumstance for a peculiar advantage in the use of this machine, which will sustain a weight, or press upon a body against which it is driven, after the power is removed or ceases to act. To enumerate all the uses of the screw would be impossible. Among other purposes, it is applied to great advantage for measuring or subdividing small spaces; when thus applied it is called a *micrometer*, which may be made to indicate on an index plate, a portion of a turn, advancing the screw less than the fifty thousandth part of an inch.

The threads of screws are differently formed, according to the materials of which they are made, or the use for which they are intended. The threads of wooden screws are generally angular, that they may rest upon a broad base, and thereby have their strength increased to the utmost. Small screws, whatever material they are made of, are generally angular also, not only

for the same reason as the wooden ones, but because the anglnar thread is the most easily made. The metal screws which are used for large presses, vices, &c. generally have a square thread, a form which gives great steadiness of motion. A thread, of which the sides are parallel, and the top and bottom a little rounded, is perhaps the most perfect of all forms.

In the common screw, to which the preceding observations are exclusively applicable, the threads are one continued spiral, from one end to the other; but where there are two or more separate spirals running up together, as in the worm of a jack, or the principal screw of a common printing-press, the descent of the screw in a revolution will be proportionately increased; and therefore whatever be the number of the spirals, they must, in calculating the power, be measured and reckoned as one thread.

Of the Endless Screw.

A screw is sometimes cut on an axle, to serve as a pinion, and by working in the circumference of a wheel; it is then called an *endless screw*, because it may be turned perpetually without advancing or receding, that is, without any other motion than a rotary one. The threads of this screw are of the square form, and fit exactly into the spaces between the teeth of a wheel, which teeth are cut obliquely to answer to the threads. When the endless screw has been turned once round, the wheel has only made a portion of a turn equal to the distance between one of its threads, that is, the wheel has moved one tooth, and therefore the number of its teeth is always the same as the number of the revolutions made by the screw before it is once turned round.

This construction and mechanical advantage gained by this screw may be best illustrated by a figure; let the wheel C, fig. 11, pl. III, have an endless screw B, on its axis, working in a wheel D, of 48 teeth. The screw B, and the wheel C, being on the same axis, every time they are turned round by the winch, the wheel D will be moved one tooth forward by the screw, and therefore 48 revolutions of the winch will be required to turn the wheel D once round. Then, if the circumference of the circle described by the handle of the winch A, be equal to the circumference of a groove round the wheel D, the velocity of the handle will be 48 times as great as the velocity of any given point in the groove; consequently, if a line G, goes round the groove, and has a weight of 48 pounds hung to it, a power equal to one pound at the handle will balance and support that weight. If any apparatus were constructed for the purpose, this might be proved by making the circum-

ferences of the wheel C and D equal to one another; and then if a weight H, of one pound, were suspended by a line going round the groove of the wheel C, it would balance a weight of 48 pounds hanging by the line G, and a small addition to the weight H will cause it to move the weight G as in every other case after the equilibrium takes place.

If a line G, instead of going round the groove of the wheel D, goes round its axle I, the power of the machine will be as much increased as the circumference of the groove exceeds the circumference of the axle. If then the circumference of the groove, be six times greater than the circumference of the axle, one pound at H will balance six times 48, or 288 pounds, hung to the line on the axle; the power gained will therefore be as 288 to 1; and a man whose natural strength would enable him to lift one hundred weight, will be able to raise 288 hundred weight by this engine.

The use of the endless screw affords a very ready means of greatly diminishing a rotary motion, and accomplishes at once what would otherwise require the intervention of two or three wheels; and although it operates wholly by a sliding motion, it has not probably more friction than any of the less simple combinations which might be employed to effect the same object. It possesses the advantage, too, of moving a wheel with much more steadiness than a pinion, when the workmanship of both is of equal quality. This circumstance is not so much regarded by mechanics as perhaps it ought, and therefore the endless screw is often not used when it would be advantageous. Cast iron wheels are becoming increasingly general for all kinds of large machinery requiring wheel-work. Their durability, and the little room they take up, when compared with the wooden ones, to answer the same purpose, entitle them to a decided preference; but still there are many great impediments to their being made true. They must necessarily partake of the defects of the pattern made for casting them; very few millwrights make good patterns, and even their best efforts are sometimes rendered, in some measure, abortive by the warping or shrinking of the wood they have used. But supposing all difficulties with respect to the pattern to be conquered, the liability to incorrect work from the imperfections of the mould, the presence of stagnated air, and the unequal contraction of different portions of the metal, are very considerable, and never absolutely overcome by the most careful workmen. It is true that cast iron wheels are better than any other, and that they may be rectified by hand; but this operation, if carried beyond a certain point, would prove very expensive; it is besides for other reasons indesirable, and seldom

attempted in any great degree, because, as the surface of cast iron is far harder than the interior, it would remove that portion of the metal which always wears the best. Whoever, therefore, attends to the motions of machinery, will frequently observe some parts to move by jolts or starts; the cause of which is, the inaccuracy of the teeth or cogs. In consequence of this, engineers, when they want a steady motion, as for a lathe, resort to the expedient of employing a large train of wheels. They thus commonly attain their prime object, for the probability is, that opposite imperfections will balance each other; but they have introduced a great increase of friction, and a consequent necessity for a greater motive force, not to mention the expense of the additional parts of the machinery. To avoid in part these disadvantages, they might more frequently employ the endless screw, for the reasons already alleged. The principal restriction to the use of this screw is, its being so liable to wear when its motion is very rapid; a rapid motion, therefore, should not be assigned to it unless it be made of hardened steel, when the objection will not apply.

Of Compound Machines.

When two or more of the simple mechanical powers are made to act in conjunction, to produce a given effect, the contrivance resulting from the union is called a *compound* machine or engine.

Though any one of the mechanical powers is capable of overcoming the greatest possible resistance in theory; yet, in practice, if used singly, they would frequently be so unmanageable as to render their properties nugatory. It is therefore generally found best to combine them together; by which means the power is more easily applied, and many other advantages obtained.

As the mechanical powers, in whatever manner they are combined, still preserve their properties; so, in compound as in simple engines, whatever is gained in power is lost in time; consequently, if a given power will raise one pound with a given velocity, it will be impossible for that power, by the help of any machine, to raise two pounds with the same velocity; yet, by the assistance of a machine, two pounds may be raised with half that velocity, or one thousand pounds with a thousandth part of it; but still there is no greater quantity of motion produced when a thousand pounds are moved, than when only one pound is moved; because the greater weight moves proportionately slower than the lighter. The power, then, of machines, consists only in this, that by their means the velocity of the weight may be diminished at pleasure, so that with a

given force any given resistance may be overcome; and the advantages they afford us are confined to convenience; for instance, by machines, we are enabled to assign a convenient direction to the moving power, and to apply its action at some distance from the body to be moved, which are circumstances of the highest importance. By machines, also, we can so modify the energy of the moving power, as to produce effects not otherwise obtainable.

In contriving machines, simplicity of parts should always be studied; for in general the more complex they are, the more frequently they are out of order, and the more difficult to repair; the more expensive also at first, and the greater their friction, from the number or extent of their rubbing parts. A very complex engine may indeed be a proof of the ingenuity of the inventor; but if that be all, as soon as a more simple mode of effecting the same purpose shall be known, the precarious tenure of his celebrity will soon be evident, and he will be convinced that ingenuity without science is exerted to very little purpose; and the display of science is always the more complete, the fewer the parts of a machine, or the more simple the means by which a given purpose is attained.

To those who have a mechanical invention in view, and who are as yet possessed of little practical knowledge, it may prevent some disappointment to observe, that the performance of the models, or small machines made for the sake of trial, may equal their expectations, yet the action of such a machine upon a large scale, may not prove permanently advantageous, nor perhaps capable even for a short time of supporting an analogous action. A large machine has not the same relative strength as a small one; it frequently admits not of the same excellence of workmanship, and in general it cannot be made of materials so durable or possessed of so little friction. On the contrary, it will sometimes happen, that a model will perform indifferently, though a large machine on the same plan will give satisfaction; this may occur, when some of its parts are so minute, and of such a description, that a common degree of manual skill is insufficient to form them correctly. Experience alone can effectually teach the art of making the proper allowances in these different cases; and the mere study of the theory of the mechanical powers, will therefore supply the mechanic with but a small portion of the knowledge which he ought to possess.

To discover the mechanical power of any engine, it will be sufficient to measure the space described in the same time by the power and the resistance, or weight; for the power always

balances the weight, when it is in the same proportion as the velocity of the weight to the velocity of the power. Or, divide the machine into all the simple ones of which it is formed; then begin at the power and call it one, and by the properties of the mechanical powers find the forces in numbers which the first simple machine exercises upon the second. Call this force one, and find the force in numbers with which it acts upon the third; and putting this force as one, ascertain its action on the fourth in numbers, and so on to the last. Then multiply all these numbers or individual ratios of the power to the weight together, and the product will be the force of the machine, supposing the first power to be one. This has been exemplified by the method of calculating the power of a compound lever.

In wheel-work, it is evident from the principles already laid down, that the velocity of a wheel is to that of a pinion, or smaller wheel which it drives, or by which it is driven, in proportion to the diameter, circumference, or number of teeth in the pinion to that of the wheel. If then the teeth in a wheel amount to 80, and the leaves in a pinion to ten, the pinion will go 8 times round for one revolution of the wheel, because 80 divided by 10, gives 8 for the quotient.

If the product of the teeth in any number of wheels acting on so many pinions, be divided by the product of the teeth or leaves in the pinions, the quotient will give the number of turns of the last pinion in one turn of the first wheel. Thus, if a wheel A, (fig. 12, pl. III,) of 48, acts on a pinion B of 8, on the axis of which pinion there is a wheel C of 40, driving a pinion D of 6, carrying a wheel E of 36, which moves a pinion F of 6, carrying an index; then the number of turns made by the axis of the last pinion, and consequently by the index, will be found in this manner: $\frac{48}{8} \times \frac{40}{6} \times \frac{36}{6} = \frac{69120}{288} = 240$, which are the number of turns made by the index, for one turn of the wheel A.

It will be evident on a little consideration, that whatever may be the number of teeth in the wheels and pinions, if they bear the same ratio, they will give the same number of revolutions to an axis. Thus, $\frac{64}{10} \times \frac{50}{8} \times \frac{36}{6} = \frac{115200}{480} = 240$, as before. The numbers, therefore, may be varied at the discretion of the engineer, whose design must of course regulate his choice. One wheel and pinion, it is also evident, will give the same motion as many wheels and pinions, if the number of teeth contained respectively in the single wheel and pinion, bear to each other the same proportion as the product of the teeth in a train of wheels bears to the product of the teeth in the pinions belonging to that train.

When a wheel is moved immediately by the power, it is called a *leader;* and if there be another wheel or pinion on the same axis, it is called a *follower*. The leader receives, and the follower imparts the motion.

As an example of the methoa of calculating the power of a compound machine, we shall refer to the crane, fig. 4, pl. III. When the handle is affixed to the axis of the wheel H of fourteen teeth; if the length from *l* to the centre of the square end of the axis upon which it is fastened, be four times the semidiameter of the pinion H, then is the acting part of the lever four times the length of the resisting part; and it will act upon the wheel G with four times the effect of the same power applied directly to G, as for example in pulling it round by its teeth; therefore, if the man at the winch exert a power equal to thirty pounds, the effect of it on the wheel G will be equal to one hundred and twenty pounds. If then G be turned by H with a force of 120, and having two and a half times as many teeth, it only makes one revolution while H makes two and a half, its pinion will exert a force of twice 120 added one half, or 300 on the wheel F. But as the wheel F has 14 times as many teeth as the pinion by which it is driven, its revolutions will be 14 times fewer than that pinion, and the power will be proportionately increased; therefore 14 times 300, which amounts to 4,200, expresses the weight which, if appended to the circumference of the wheel F, would keep a power of 30 at the winch in equilibrium. The weight, however, is not appended to the circumference of the wheel F, but to the circumference of its axle, which being four times less, its velocity is in the same proportion diminished, and its intensity must be quadrupled to have the same effect on the power; so that 4 times 4,200, or 16,800 pounds will express the whole weight which a power of 30 pounds applied to the winch when on the axis of the wheel H, will be able to keep in equilibrium; and when the equilibrium is produced, so small an addition to the power gives motion to the weight, that it is seldom mentioned, the power which effects the equilibrium being generally spoken of as if it were actually sufficient to raise the weight. We have supposed the crane to have but one winch, but such machines are generally provided with two, one at each extremity of the same axle; and it follows, that a double intensity of power will overcome a double resistance. We have also supposed the power to be 30 pounds, because that is about the intensity of the power which one man could exert on the winch; but as, in the customary way of expressing the advantage gained by a machine, the power is considered to be 1, to suit this mode of

expression, 16,800 must be divided by 30, and we shall then have a quotient of 560, which number is to 1, as 16,800 is to 30, and it shews how much the velocity of the power exceeds that of the weight, when the velocity of the latter is 1,—the difference of these velocities denoting the power of the machine, and being synonimous with the expression, that a power of one pound would raise 560 pounds.

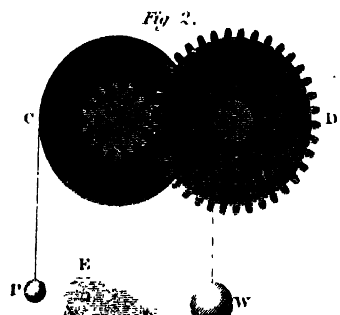
Another mode of estimating the power of the crane, fig. 4, pl. III, will be, instead of proceeding from wheel to wheel, to divide 3420, the product of the teeth in the wheels F and G, by 98, the product of the teeth in the wheel H, and the pinion on the axis of G; the quotient of this division will be 35, which, if multiplied by 4, the difference between the radius of the circle described by the winch and the radius of the wheel H; and again by 4, or the difference between the radius of the axle round which the chain coils, and the radius of the wheel F;—the product will as before be 560 for the power gained.

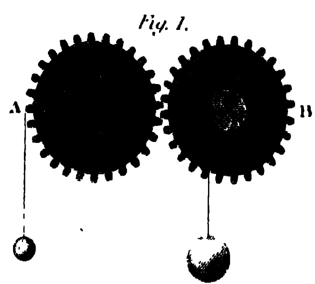
The practical application of mechanics to the construction of machinery, is a subject of the utmost importance to our country; the prosperity of which materially depends upon its commerce; its commerce is derived chiefly from its manufactures; and some of its most important manufactures are indebted to the general introduction of machinery for the preference they every-where receive. It is to this source we must attribute the increase of property of every description, as the introduction of a machine is a virtual creation of all the work it will perform without further increasing human labour. Among many, it is a prevalent opinion, that machinery is prejudicial to the interests of mankind, from its supposed tendency to diminish the amount of that labour by which the lower classes of society can alone purchase the means of subsistence. This opinion is, however, erroneous, as applied to society in general; though individuals, whose labours are superseded by machines, may suffer inconvenience for a time, yet it is only for a time, and until they, or others more intelligent, discover a new channel for the exertion of their industry. If improvements in machinery enable our manufacturers to offer their goods at lower prices than before, these goods will command a sale in foreign markets where it was previously useless to carry them. The result of their success will give them, and consequently their country, an accession of capital; and the inevitable operation of an accession of capital, will be for the advantage of the labouring classes, because it can no way be expended, without increasing the general amount of labour, and therefore making them in the end full participators in its benefits. Thus are the real interests of all ranks inseparately

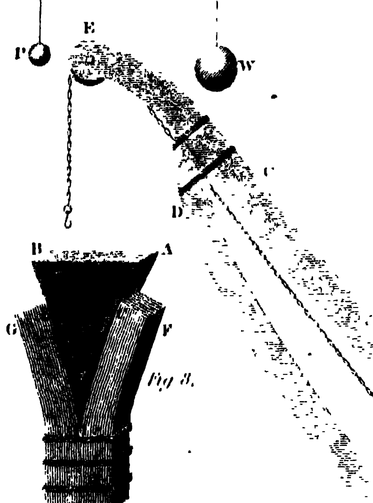
connected; and a retrospect of the last forty years will shew, that though so many machines have been employed in all trades and manufactures, as probably to do more work than the whole population could do previous to that period, yet the value of human labour has increased in the same proportion as other articles have advanced in price, except so far as this natural tendency of things has been checked by the regulations of war. As machines tend to increase the quantities of those luxuries and necessaries of life which mankind are so anxious to obtain, it only requires that an equitable division of these benefits should be effected, and then every objection to them will be obviated. But such a division is not to be obtained by the infatuated violence of individuals, nor by legislative or municipal constraints. On the contrary, this benefit can only spring with full vigour from the ashes of all monopolies, combinations, or exclusive immunities in trade. Let every individual be at all times free from the least restriction or check in the pursuit of any business consistent with the common weal, every one would be a gainer by the change; if one source of employment failed, abundance of other sources would still be open; reward would be proportioned to ingenuity; every branch of art would be occupied by those who were led to it more by choice than accident, and who were anxious to excel as much for their credit as from necessity. The aspect of the country would then be improved; more cheerful industry would enliven it; that laxity of moral conduct which is produced by insubordination, and fostered by the protecting arm of injudicious immunities, would cease to be so flagrant, if it did not disappear; and the advancement of machinery, far from being viewed by any class with malignant eyes, would be regarded as an increasing and inexhaustible source of national prosperity.

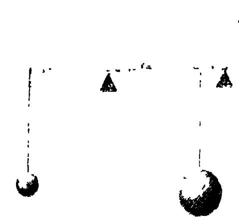
If we supposed the preceding observations on the utility of machinery were not radically true, it would be an invidious task to pursue the present subject; but unassailed by any apprehension of this kind, we shall make them the prelude to some general remarks which may be useful to the young mechanic.

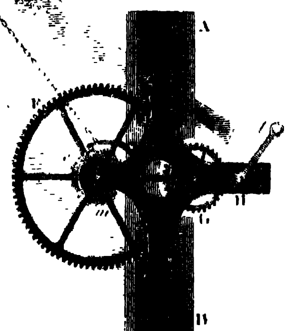
In contriving machinery, it should always be remembered, that nothing will contribute more to its perfection, especially if it be massive and ponderous, than great uniformity of motion. Every irregularity of motion wastes some of the impelling power; strains, jolts, and whatever occasions a vibratory motion of the parts within themselves, weaken the cohesion of the most solid substances, and are particularly injurious to cast iron, and the pressures at the communicating points are

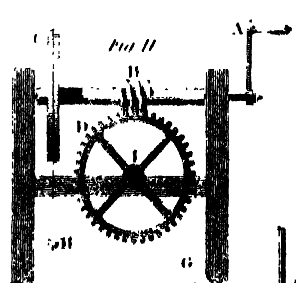

Fig 2.
C
D
P
W

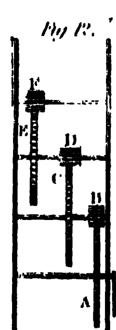

Fig. 1.
A
B


E
C
D
B
A
G
F
Fig 8.

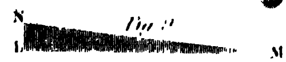


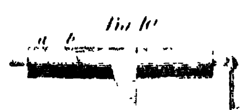

A
E
H
G
B

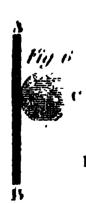

A
B
D
G


E
D
C
B
A


C
D
A
B


N
L
M




A
C
B


C
B
A

inconstant and unequal. A great engine, constructed without due regard to the uniformity of its motion, will shake the firmest building; but when uniform motion pervades the whole, the inertia of each part tends to preserve this uniformity, and all goes smoothly.

In modifying the motion of the first mover, and communicating it in a proper manner to the subject to be operated upon, the slow rotative motion of a water-wheel is, by the machinery of cranks, levers, and toothed wheels, converted into a rapid reciprocating motion for working saws; and the velocity of the motion is increased or diminished, as the occasion requires either great power or great speed. In like manner, the rectilinear motion of the piston rod of a steam engine is, by the machinery of parallel levers, working beam, connecting rod, crank and fly-wheel, converted into a rotative motion; and this motion is again, by the machinery of wheel-work, adapted to work grinding stones, circular saws, threshing mills, and other similar machines which require great velocity; or flatting mills, boring machines, machines for rasping dyewoods, drawing lead pipe, &c. which require great power to give them motion, and are therefore performed with less velocity.

In modifying a rotary motion, toothed wheels are most generally employed; and if the teeth are properly formed, wheels, perhaps, consume less force in friction than any other mode of transmitting motion. In forming the teeth of wheels, a deviation from the perfect form is of most importance where a very large wheel drives a very small one, a case the judicious engineer should always endeavour to avoid. It is of great importance to make all the teeth of a wheel precisely equal, and to make as great a number of them as the necessary strength will allow. The greater the number of the teeth, the less will be the time that any one of them will act upon its fellow, and several teeth being in action at once, will cause the communication of the motion to be extremely smooth and uniform. To obtain strength, when the cogs are made fine, the width or thickness of the wheel must be increased; and this is one of the greatest practical improvements which have been made in machinery for twenty years past. When the teeth are far apart, three, four, or five inches, for example, they always act unequally upon each other, in consequence of the point of contact altering its position, becoming alternately nearer or farther from the centre of one or other of the wheels; the acting radius of one is thus increased, while that of the other is diminished, and their velocity and powers varying in consequence with every cog that passes by, the machine works by starts

and jerks. Wheels are found to work most smoothly, when the teeth of the large wheel are made of hard wood, and the teeth of the small one of cast iron.

A rotary motion is very frequently transmitted by means of an endless strap, or belt, particularly when a very quick motion is to be created, and the re-action to be overcome is nearly equable. In such cases, it has the advantage of wheel-work from its simplicity, the ease of its motion, and the distance to which it may be conveyed. A strap should always work on a pulley which is highest in the middle of its circumference, otherwise it will be exceedingly apt to slip off. If one of the pulleys is stopped while the strap is moved round by the motion of the other, the strap instantly flies off its pulley, unless the breadth of the circumference of the pulley greatly exceeds that of the strap. This property is a great recommendation of it on many occasions, where the machines might be much injured or destroyed if driven by wheel-work and accidentally stopped. Straps should be of an equal thickness and breadth throughout. They are mostly joined by sewing; but the best method is by gluing them together, with a glue compounded of Irish glue, isinglass, ale grounds, and boiled linseed oil. The ends that overlap should be pared thin, tapering to the edge in the form of an inclined plane, so that the juncture, when they are placed upon each other, shall be no thicker than the rest of the strap.

The wheels which are turned by straps never make quite so many revolutions as they ought to do from a calculation of the diameters of the pulleys over which the straps pass. Sometimes the straps may slip a little, but the principal source of the error has been ingeniously attributed to their elasticity, which permits them to stretch on that side which bears the strain (called the leading side) and to collapse on the returning side. This error, if elasticity be the cause of it, will augment with the intensity of the strain, and the distance between the pulleys; but its utmost amount is so small as to be rarely of any great consequence.

Bands of rope or catgut are frequently employed to communicate motion, particularly to the mandrels of lathes. Catgut is the best material known for a band, and always to be preferred when it can be had of sufficient strength for the purpose: the ends are united by a small steel hook and eye, each of these has a socket screw to receive the band, which is tapered a little, and screwed into it with a little rosin. If the hook and eye be made warm enough to keep the rosin fluid during the fastening, the band will be very firm, though it may, for further security, be seared with a hot wire on the

extremity projecting through the socket. The groove of pulleys intended to receive a band, should be of a sharp angular form, that the band may not touch the bottom of it, in which case it would be liable to slip. Wood is the best material for pulleys, because the polish soon acquired by metals prevents the band from holding firmly. The wood for a pulley should be cut endways, that is, with its grain in the direction of its axis, so that every part of the circumference being of a similar texture, it will wear equally. Two methods of applying a band present themselves: in one of them it is carried over parts of the wheel and pulley corresponding in position, the upper part of the band passing directly to the upper part of the pulley, and the lower part to the lower part; but in the other method, the band is crossed, and therefore it passes from the upper part of the wheel to the under part of the pulley. A crossed band answers the best end; for as it envelopes a larger portion of the pulley, it produces a better effect than the other, even when not so tight.

Endless chains are sometimes used to communicate motion, and where their slipping would be injurious, cogs are frequently formed on the wheels, to be received into the links of the chain. The links should be formed with great exactness.

For very light machinery, a very neat and even elegant mode of communicating motion has long been partially in use; it consists in covering the circumferences of the wheels with buff leather, which creates sufficient friction to make them turn each other freely, although not pressed very hard together. The same principle has been adopted upon a large scale for a saw-mill, in which the wheels acted upon each other by the contact of the end grain of wood instead of cogs. The machinery wore well, made little noise, and was in use twenty years. When this mode of transmitting power is adopted, a contrivance to make the wheels bear firmly against one another, either by wedges at the socket, or by levers, must be included.

It requires all the art of the engineer, when reciprocating and desultory motions are required, to introduce them in the most advantageous manner. Eccentric wheels are frequently employed, but the common crank is perhaps the most lastingly useful (principally on account of its being the most simple) contrivance, for converting a reciprocating motion into a circular one, or the contrary. Attempts have been made to move the pistons of pumps by means of a double rack on the piston rod; a half wheel takes hold of one rack, and raises it to the required height; the moment the half wheel has quitted that side of the rack, it lays hold of the other side, and forces the piston down again. This has been proposed as a great im-

provement, by correcting the unequal motion of the piston, moved in the common way by a crank motion; but it occasions such abrupt changes of motion, as to be wholly inadmissible in practice; the more ponderous the machine, and the more correct its workmanship, the sooner it would shake it to pieces.

When heavy stampers are to be raised, in order to drop on the matter to be pounded, the wipers by which they are lifted, should be made of such a form, that the stamper may be raised by a uniform pressure, or with a motion almost imperceptible at first. If this is neglected, and the wiper is only a pin sticking out from the axis, the stamper is forced into motion at once. This occasions a violent jolt to the machine, and great strains on its moving parts and their points of support; whereas, when they are gradually lifted at first, the inequality of desultory motion is never felt at the impelled point of the machine. The principle, however, of communicating the motion gradually may be carried too far. In order to avoid the great inconvenience arising from the abrupt motion given to a great sledge hammer of seven hundred weight, resisting with a five-fold momentum, an engineer formed the wipers for lifting it into spirals, which communicated motion to the hammer with scarcely any jolts whatever; but the result was, that the hammer rose no higher than it had been raised in contact with the wiper, and then fell on the iron with very little effect. Wipers of the common form were therefore of necessity substituted for the spirals; for in this operation the rapid motion of the hammer, during the greater part of its progress, is absolutely necessary; it is not enough to lift it up; it must be flung up so as to rise higher than the wiper lifts it, and to strike with great force the strong oaken spring which is placed in its way. It compresses this spring, and is reflected by it with a considerable velocity, so as to hit the iron as if it had fallen from a great height; had it been allowed to fly to that height, it would have fallen upon the iron with somewhat more force, (because no spring is perfectly elastic) but twice the time would have been required.

All ponderous movements should be supported by a framework of wood, or of iron upon wood, independent of the building of masonry or brick-work containing them. The want of attention in this respect, has not unfrequently occasioned buildings to be shaken to pieces. If the gudgeons of a waterwheel, for example, rest upon the wall of a building recently erected, it can scarcely fail to prevent the perfect induration of the mortar, and the strength of the wall will thus be completely crippled. If such a situation must be selected, the gudgeons should be supported upon a block of oak laid a little hollow. This will soften all tremors, like the springs of a

carriage, and a prudent extension of the principle would be very serviceable in many parts of the construction.

To avoid the injurious effects occasioned by urging suddenly or by jerks the parts of a ponderous machine from a state of rest into a state of motion, an ingenious contrivance has lately been introduced, which deserves to be generally known. The arm which gives motion to the machine, when the clutch or connecting part of the running spindle is engaged with it, is not fixed fast upon the spindle, but is made in two halves screwed together upon a cylindrical part of the spindle, and so closely pinched upon it by screws, that it will have sufficient friction to turn the machine round in the ordinary course of its work, but slips round upon the spindle, if the resistance is greater than this friction, which thus becomes the measure of the power exerted upon the machine.

Contrivances for uniting or detaching motions are very various. The supports of the gudgeons of toothed wheels are sometimes fitted up so as to be moveable, so that the wheels can be separated so far as to relieve each other's teeth. At other times one of the wheels is fitted on a round part of its axis, and united with it at pleasure, by what is called a clutch-box. Thus the wheels are always in motion, but one of them can be detached at pleasure from its axis, on which it slips freely. Bevelled cog-wheels are easily disengaged, by moving the axis of one of them a little endways. For disengaging the motion of a strap, the contrivance called the live and dead pulley is very ingenious and effectual; it consists of two pulleys placed close together upon any axis which is to receive a circular motion. One of them is fast upon the spindle, and the other loose, so as to slip round. It is necessary that the wheel by which these pulleys are turned, should have its rim at least equal in breadth to that of both the pulleys. This contrivance is extensively used, and, as applied to a lathe, has been described in the section on Turning.

It is frequently necessary in machinery to have the power of reversing the motion of a wheel or axis at any required interval. Various means are used for effecting this object. The most common is by two equal and similarly bevelled or contrate wheels, situated on the same axis, with their teeth towards each other. A third bevelled wheel is applied with its axis perpendicular to these; and as its teeth, by simply moving a lever, can be made to engage either of them at pleasure, they will, as they act on contrary sides of this third wheel, communicate to it opposite motions. Smeaton applied this movement to draw coals from coal-pits.

Of Fly Wheels.

In all machines, the moving power and the resistance are subject to fluctuations of intensity. It becomes, therefore, an object of great moment, to have, in most compound machines, some means of accumulating the excess of the motive power, and of expending this excess, when the motive power operates too feebly. This equalization of motion is usually obtained by what is called a *fly*, which is generally made in the form of a wheel, though sometimes it is merely two bars crossing one another at right angles in the middle, with weights at the four extremities.

A fly being made to revolve about its axis, keeps up the force of the power, and distributes it equally in all parts of its revolution. On account of its weight, a small variation in force does not sensibly alter its motion; whilst its friction, and the resistance of the machine, prevents it from accelerating. If the motive power slackens, it impels the machine forward, and if the power tends to move the machine too fast, it keeps it back.

In all machines in which flies are used, either a considerably greater force must be applied at first than what is necessary to give motion to the machine without it, or the fly must be set in motion some time before the force is applied to the machine. This superfluous power is collected in the fly, which is in fact a reservoir of motion. A man, working at a common windlass, exerts a very irregular pressure on the winch. In two of his positions, during each turn, he can exert a force of nearly seventy pounds without fatigue, but in other positions he exerts a force of little more than twenty-five pounds; nor must he in general have to oppose much above this; but if a large fly be properly connected with the windlass, he will act with equal ease and speed against thirty or even forty pounds.

The motion communicated to a fly-wheel by means of a small force, may be accumulated to such a degree as to produce effects which the original force would never have accomplished. Atwood has demonstrated in his "Treatise on Rectilineal and Rotary Motion," that a force equivalent to 20 pounds, applied for the space of 37 seconds to the circumference of a cylinder 20 feet in diameter, which weighs 4713 pounds, would, at the distance of one foot from the centre, give an impulse to a musket-ball equal to that which it receives from a full charge of powder. In the space of six minutes and ten seconds, the same effect would be produced, if the wheel were driven by a man, who constantly exerted a force of 20 pounds at a winch one foot long. This accumulating power of a fly, induces

among many a supposition, that a fly really adds power or mechanical force to an engine; accordingly, from not understanding on what its efficacy depends, nor considering, that if it communicated a power which it did not receive, it must, contrary to the nature of matter, possess a principle of motion within itself, they often place the fly in a situation where it only adds a useless burden to the machine. If intended for a mere regulator, it should be near the first mover; if intended to accumulate force in the working point, it should not be far separated from it.

It is certain, that a fly does not communicate any absolute increase of motion to the machine; for if a man, or any animal, is not able to set an engine in motion without a fly, he will not be able to do it though a fly be applied; nor will he be able to keep it in motion, though set to work with a fly by means of a greater power. The apparent creation of power by a fly consists in its accumulating into one moment, the exertions of many. A man, caught by some of the movements of a country mill, may be instantly deprived of a limb, or of life. In this case, the power of the stream is conceived to be prodigious, and yet we are certain, upon examination, that it amounts to the pressure of no more than fifty or sixty pounds; but this force has been acting for some time, and there is a millstone of a ton weight whirling twice round in a second; the effect, therefore, not of any self-derived but of the accumulated power, is enormous. Contrivances to prevent accidents from the force of machinery, deserve every encouragement; and perhaps, among the improvements yet to be made in practical mechanics, they will be more conspicuous than they have hitherto been. It has been asserted, that in the neighbourhood of Elbingroda, in Hanover, there was a contrivance which disengaged the millstone when any thing got entangled in the teeth of the wheels. On being tried with the head of a cabbage, it crushed it, but not violently, and would by no means have broken a man's arm.

The resistance which the air opposes to any body in motion, and the friction of the pivots which support the axis of a fly, are considerable deductions from the power communicated to this appendage of machinery, so that instead of really gaining power, a fly-wheel requires a constant exertion to keep it in motion, even when no further resistance is applied to prevent it. For this reason, a fly-wheel should never be introduced into a machine unless the advantages to be derived from its action are greater than the actual loss of power it occasions. In general, where the power is tolerably uniform in its action, if the resistance can be made so too,

a fly is not necessary. If two hammers are raised at the same moment by a water-wheel, during the interval of their descent much power would be lost, unless it were collected by a fly; but if the two hammers, or any other number, were raised in succession, the resistance would be rendered nearly as uniform as with a fly-wheel, without its inconveniences.

A fly for the accumulation of power, should be so constructed as to present the smallest resistance to the air. A wheel is the best form; it should be made of metal, that it may have a great weight under a small surface, and it should be smooth and truly circular, without any projecting nuts. If the transverse section of the rim be a circle, and the transvere sections of the arms connecting the rim with the centre, be ellipses, presenting their thin edge to divide the air, the fly will be less resisted by the air than under any other form. This configuration of a fly is included in a patent taken out by Murray and Wood, of Leeds.

Fly-wheels are usually made of iron; when they are too large to be cast in one piece, it is very important to unite the parts in the most substantial manner; for the centrifugal force of a great wheel in rapid motion is prodigious, and if the bolts be insufficient to withstand the strain upon them, the parts broken off will be projected with a velocity giving them the destructive power of a cannon-shot.

Suppose a fly be employed in a machine required to raise a pestle of thirty pounds weight to the height of one foot sixty times in a minute; here the weight of a fly is a principal object, and its effect is calculated by a comparison with the weight to be raised. Let the diameter of the fly be seven feet, and supposing the pestle to be raised once by every revolution, we must then consider what weight, passing in one second, through a space equal to the circumference of the fly, which is about 22 feet, will be equivalent to 30 pounds passing through one foot in a second. This will be 30 divided by 22, or $1\frac{8}{22}$. Were a fly of this kind applied, and the machine set in motion, it would be able to lift the pestle once after the moving power was withdrawn; but by increasing the weight of the fly to ten, twelve, or twenty pounds, the machine, when left to itself, would make a considerable number of strokes, and after the incumbrance of the fly at the outset was overcome, it would be worked with much less labour than if no fly had been used. The mode of calculation here adopted, is equally applicable to the motion of pumps; but the weight which can be most advantageously given to a fly has never been satisfactorily determined.

Of Friction.

With the exception of a few incidental remarks, we have hitherto paid no attention to the physical properties of the materials of which machines are composed, and of the alterations those properties occasion in the effects established by theory alone. This was necessary, to disentangle the theory from the constant recurrence of provisoes and limitations, which would be best understood if distinctly considered; but we must now proceed to point out the impediments to the perfect action of machines, and the allowances to be made for them.

Among the various physical causes which occasion a difference between theory and practice, with respect to machines, the two following may be considered the most important and most general: 1. The weight of the parts composing the machines. 2. Friction, a term which designates the obstruction to the motion of a machine, produced by the resistance of the air, as well as that produced by the rubbing of one part against another. In trying experiments to exemplify the theory of the lever, it has been shewn that the shorter arm must be made as heavy as the longer arm, otherwise they will not perfectly succeed. This shews the principle on which allowances must be made for the weight of machinery, and how this cause of obstruction may be obviated. Friction is, however, a cause of obstruction always present; it may be diminished by various artifices, but never entirely removed.

Leslie, in his valuable work on the nature and propagation of heat, adverts to the cause of friction in a very able manner: "If the two surfaces," says he, "which rub against each other, are rough and uneven, there is a necessary waste of force, occasioned by the grinding and abrasion of their prominences. But friction subsists after the contiguous surfaces are worked down as regular and smooth as possible. In fact, the most elaborate polish can operate no other change than to diminish the size of the natural asperities. The surface of a body being moulded by its internal structure, must evidently be furrowed, toothed, or serrated. Friction is, therefore, commonly explained on the principle of the inclined plane, from the effort required to make the incumbent weight mount over a succession of eminences. But this explication, however currently repeated, is quite insufficient. The mass which is drawn along is not continually ascending; it must alternately rise and fall: for each superficial prominence will have a corresponding cavity; and since the boundary of contact is supposed to be horizontal, the total elevations will be equalled by their collateral depressions; consequently, if the lateral force might

suffer a perpetual diminution in lifting up the weight, it would, the next moment, receive an equal increase by letting it down again; and those opposite effects, destroying each other, could have no influence whatever on the general motion.

"Adhesion seems still less capable of accounting for the origin of friction. A perpendicular force acting on a solid, can evidently have no effect to impede its progress; and though this lateral force, owing to the unavoidable inequalities of contact, may be subject to a certain irregular obliquity, the balance of chances must, on the whole, have the same tendency to accelerate, as to retard, the motion. If the conterminous surfaces were, therefore, to remain absolutely passive, no friction could ever arise. Its existence demonstrates an unceasing mutual change of figure, the opposite planes, during the passage, continually seeking to accommodate themselves to all the minute and accidental varieties of contact. The one surface being pressed against the other, becomes, as it were, compactly indented, by protruding some points and retracting others. This adaptation is not accomplished instantaneously, but requires very different periods to attain its *maximum*, according to the nature and relation of the substances concerned. In some cases a few seconds are sufficient; in others, the full effect is not produced till after the lapse of several days. While the incumbent mass is drawn along, at every stage of its advance, it changes its external configuration, and approaches more or less towards a strict contiguity with the under surface. Hence the effort required to put it first in motion; and hence, too, the decreased measure of friction, which, if not deranged by adventitious causes, attends generally an augmented rapidity. This appears clearly established by the curious experiments of Coulomb, the most original and valuable which have been made on that interesting subject. *Friction consists in the force expended to raise continually the surface of pressure by an oblique action.* The upper surface travels over a perpetual system of inclined planes; but that system is ever changing with alternate inversion. In this act, the incumbent weight makes incessant, yet unavailing, efforts to ascend: for the moment it has gained the summits of the superficial prominences, these sink down beneath it, and the adjoining cavities start up into elevations, presenting a new series of obstacles which are again to be surmounted; and thus the labours of Sisiphus are realized in the phenomena of friction.

"The degree of friction must evidently depend on the angles of the natural protuberances, and which are determined by the elementary structure or the mutual relation of the two approximate substances. The effect of polishing is

only to abridge those asperities and increase their number, without altering in any respect their curvature or inflexions. The constant or successive acclivity produced by the ever-varying adaptation of the contiguous surfaces, remains, therefore, the same, and consequently the expense of force will still amount to the same proportion of the pressure. The intervention of a coat of oil, soap, or tallow, by readily accommodating itself to the variations of contact, must tend to equalize it, and therefore must lessen the angles, or soften the contour, of the successively emerging prominences, and thus diminish likewise the friction which thence results."

The friction of a single lever is very trifling. The friction of the wheel and axle is in proportion to the weight, velocity, and the diameter of the axle; the smaller the diameter of the axle, the less will be the friction.

Pulleys have very great friction, on account of the smallness of their diameters in proportion to that of their axles, and their friction is greatly increased when they bear, as they are very apt to do, against their blocks, and when their centres and axles are worn untrue.

The friction of bodies is in general proportionate to their weight, or the force with which their rubbing surfaces are pressed together; and is for the most part equal to between one-half and one-fourth of that force. Although friction increases with an increase of surface, yet this does not take place in direct proportion to that increase. It also increases, with some exceptions, in proportion to the velocity of bodies, particularly when very different substances are employed without an unguent.

According to Emerson, when a cubical piece of soft wood, of eight pounds weight, moves upon a smooth plane of soft wood, at the rate of three feet per second, its friction is about one-third of its weight; but if it be rough, the friction is little less than half the weight: on the same supposition, when both the pieces of wood are very smooth, the friction is about one-fourth of the weight; the friction of soft wood on hard, or of hard wood on soft, is one-fifth or one-sixth of the weight; of hard wood upon hard wood, one-seventh or one-eighth; of polished steel moving on steel or pewter, one-fourth; moving on copper or lead, one-fifth of the weight.

It was generally supposed, that in the case of wood, the friction is greatest when the bodies are dragged contrary to the course of their fibres; but the experiments of Coulomb demonstrate the contrary.

The longer the rubbing surfaces remain in contact, the

greater is their friction. When wood was moved upon wood according to the direction of the fibres, the friction was increased by keeping the surfaces in contact for a few seconds; and when the time was prolonged, to a minute, the friction seemed to have reached its farthest limit. But when the motion was performed contrary to the course of the fibres, a greater time was necessary before the friction arrived at its maximum. When wood was moved upon metal, the friction did not attain its maximum till the surfaces continued in contact for four or five days; and it is very remarkable, that when wooden surfaces were anointed with tallow, the time requisite for producing the greatest quantity of friction was increased. The increase of friction which is generated by prolonging the time of contact is so great, that a body weighing 1650 pounds was moved with a force of 64 pounds when first laid upon its corresponding surface. After having remained in contact for the space of three seconds, it required 160 pounds to put it in motion, and when the time was prolonged to six days, it could scarcely be moved with a force of 622 pounds. When the surfaces of metallic bodies were moved upon one another, the time of producing the greatest effect or maximum of friction was not changed by the interposition of olive oil; more time, however, was required to produce the maximum when swine's grease was employed as an unguent; and it was prolonged to five or six days when the surfaces had been besmeared with tallow.

In wood rubbing upon wood, oil, grease, or black-lead, properly applied, makes the friction two-thirds less. Wheel naves, when greased, have not more than one-fourth of the friction they would have if only wetted.

When polished steel moves on steel or pewter, properly oiled, the friction is about one-fourth of the weight; on copper or lead, one-fifth of the weight; on brass, one-sixth; and metals have more friction when they move on metals of the same kind, than when they move on different metals. This seems principally owing to the superior strength of the attraction of cohesion between similar metals. It is always desirable, therefore, to make the parts of machines opposed to or working in each other, of different materials; thus, in clocks and watches, the wheels are brass, and the pinions steel, and iron pivots are made to work in brass or bell-metal collars. The axes of wheels should also be made as small as the weight they have to bear will allow; because the diminution of the surfaces rubbing against each other, will be attended with a diminution of the friction.

According to Vince's experiments, which were made with

great care, and frequently repeated, the friction of *hard* bodies in motion is a uniformly retarding force. Experiments were instituted to determine whether the same law obtained when the bodies were covered with cloth, woollen, &c. and it was found, in all cases, that the retarding force increased with the velocity; but on covering the bodies with paper, the results agreed with those before stated. By other experiments, the same philosopher found, that the quantity of friction, contrary to the prevailing opinion, increased in a less ratio than the quantity or weight of the body; also, that the smallest surface has the least friction. It may be proper to describe the apparatus by which these results were obtained: a plane was adjusted parallel to the horizon; at the extremity was placed a pulley, which could be elevated or depressed, so as to render the string which connected the body and the moving force, parallel to the plane. A divided scale was placed near the pulley, perpendicular to the horizon; and the moving force descended by the side of this scale. A moveable stage was placed upon the scale, which could be adjusted to the space through which the moving force descended in any given time, which time was measured by a well regulated pendulum, vibrating seconds.

According to Coulomb's experiments, which were conducted on a large scale, and are therefore much relied on, the friction of lignum-vitæ cylinders, two inches in diameter, and loaded with one thousand pounds, was 18 pounds, or nearly $\frac{1}{56}$ of the weight or force of pression. In cylinders of elm, the friction was greater by $\frac{2}{3}$, and was scarcely diminished by the interposition of tallow. From a variety of experiments on the friction of the axes of pulleys, the following results were obtained; when an iron axle moved in a brass bush or bed, the friction was $\frac{1}{6}$ of the pression; but when the bush was besmeared with very clean tallow, the friction was only $\frac{1}{11}$; when swine's grease was interposed, the friction was about $\frac{1}{8}$, and when olive oil was employed, it was about $\frac{1}{7}$. When the axle was of green oak, and the bush of lignum-vitæ, the friction was $\frac{1}{26}$ when tallow was interposed; but when the tallow was removed, so that a small quantity of grease only covered the surface, the friction was increased to $\frac{1}{17}$. When the bush was made of elm, the friction was, in similar circumstances, $\frac{1}{3}$ and $\frac{1}{40}$, which is the least of all. When the axle was made of box, and the bush of lignum-vitæ, the friction was $\frac{1}{23}$ and $\frac{1}{14}$, circumstances being the same as before. If the axle be of boxwood, and the bush of elm, the friction will be $\frac{1}{29}$ and $\frac{1}{20}$; and if the axle be of iron, and the bush of elm, the friction will be $\frac{1}{20}$ of the force of pression.

In calculating the force of an engine, friction should never be overlooked. Though it varies so much with circumstances, that it is not yet reduced to certain rules, still the specific details we have given will enable the young mechanic to come tolerably near the truth, in ascertaining its amount, at each part of a machine, according to the pressure, surface, and materials; and as he goes along from the power to the resistance, he must consider these amounts as actual deductions from the advantage of the machine. It must be understood, that the amount of friction stated in this section, will apply only to machines that are well made; the loss of power that may be occasioned by bad workmanship is incalculable, and as bad workmanship may exist when it is not perceived, no conjectural calculation should be relied on, when the real loss of power can be obtained by experiment.

One general rule of preventing friction is to substitute, whenever it is possible, the rolling for the sliding motion. Every one knows that a weight which the application of a given force cannot drag, may be easily drawn along by the same force, if mounted upon wheels turning on their axes. On this principle depends the utility of what are called friction rollers, which are small cylinders or spheres interposed so as to revolve between surfaces that would otherwise rub upon each other; or small wheels so disposed that the pivots of larger wheels revolve upon their circumferences, instead of turning in a bush or socket. Three wheels, it is obvious, if they touch the different sides of the pivot in three points equidistant from each other, will support it as effectually as a cylindrical socket, which would have far greater friction. When the motion to which these rollers or wheels are subjected, is equal and steady, the use of them will often be productive of permanent advantage; but when, as for the axletrees of carriages, they are subject to violent strains, jolts, and, occasionally at least, to enormous pressure, they are, however excellent in principle, seldom found of much practical utility, and are often positively injurious; for they and the parts bearing upon them, either do not receive from the workman the precise figure they ought to have, or if well made, they wear so unequally as soon to lose that correctness of figure which is inseparable from their value.

Of the Application of Men and Horses, as moving Powers in Machinery, &c.

A man turning a horizontal windlass by a handle or winch, should not have to exert a greater force than 30 pounds, if he have to work ten hours a day; therefore the power exhausted by friction, the stiffness of ropes, and the intensity of the resistance, should not, altogether, require more than a force of 30 pounds to overcome them.

In the operation of turning a winch, the effect of a man's force varies in every part of the circle described by the handle. The greatest force is when he pulls the handle upwards from about the height of his knees; and the least force, when, the handle being at the top, he thrusts from him horizontally; then again the effect is increased as he lays on his weight in pushing downwards; but that action is not so great as when he pulls up, because it is merely produced by the weight of his body, whereas, in pulling up, he can exert his whole strength. In pulling the handle horizontally, when at its lowest, the force exerted is very small.

The weight of a man of moderate strength, may be stated at 140 pounds, and such a person may be considered capable of exerting the following forces, viz. in the strongest point, or that position of the winch which is most favourable to him, a force equal to 160 pounds; in the weakest, a force equal to 27 pounds; in the next strong point, 130 pounds; and in the last, or second weak point, 30 pounds. The sum of these forces is 347, which, divided by 4, gives 84¾ pounds for the weight that a man might lift by a winch, if he could exert his whole strength continually, without stopping to take breath; but this being impossible, the weight must return, and overpower him at the first weak point, especially when the handle moves slowly, as it must if he would exert his utmost strength all round. Besides, in overcoming such a resistance, the man is in theory supposed to act always along the tangent of the circle of motion, which application of his force is not practicable; and there must also be such a velocity given, that the force applied at the strong points may not be spent before the hand comes to the weak ones, which is a regulation of exertion also unattainable; hence, when no adventitious advantages are superadded, the resistance ought to be no more than 30 pounds. If a fly be added to the windlass, when the motion is pretty quick, as about four or five feet per second, a man may exert for a short time a force of 80 pounds, and work a whole day against a resistance of 40 pounds.

If the windlass be provided with two handles, one at each extremity, and the elbows of these handles are at right angles to each other, two men will more easily, for the same length of time, act against a constant resistance of 70 pounds, than a single man against 30 pounds; for one man will act at the strongest point while the other acts at the weakest point of the revolution, and thus they will mutually and successively help one another. The utility of this disposition of the handles is now generally known and attended to, but it was formerly little thought of.

The whole art of carrying large burdens consists in keeping the column of the body as directly under the weight and as upright as possible. Standing in his natural posture, a man can support a weight which would break the back of the strongest horse. The reason is evident: the column of the man's bones support the weight directly; but the weight is laid across the column of the horse. The more a man bends his body, the less weight he can support; hence two men carrying a load, can sustain much more than double the weight which either of them could carry separately, because they can move more upright, and with the column of their bones more opposed to it. Chairmen having straps from their shoulders to the poles of the chair, will walk with 300 pounds (that is 150 pounds each) at the rate of four miles an hour. A porter will carry upon his shoulders a load of 180 pounds, and walk at the rate of three miles an hour; a coal-heaver will carry 250 pounds, but he only goes to a short distance with his load. In rowing, men exert their strength with great effect; and they more usually draw the oar to them than push it from them, because, in the former case, they can bring into action a greater number of muscles, and experience quickly convinces them of the best mode.

A horse draws with the greatest advantage when the line of draught is not level with his breast, but inclines upwards, making a small angle with the horizontal plane.

A horse drawing a weight over a single pulley can exert a force of 200 pounds, while walking at the rate of two miles and a half per hour, or about three feet and a half per second. If the same horse have to draw 240 pounds, he can work but six hours a day, and cannot go quite so fast. To this mode of exertion may be referred the working of horses, in all sorts of mills, in calculating the probable effect of which, previous to their being erected, after making the necessary allowances for all frictions and hinderances, the task assigned to the horse should be carefully determined.

The force with which a horse acts is compounded of his weight and muscular strength. If then the weight of one horse exceed that of another to which it is inferior with respect to strength, the weaker horse will overcome a resistance which the stronger cannot, provided the excess of his weight in the smallest degree exceeds his deficiency in strength.

When a horse draws in a mill or gin of any kind, great care should be taken that the horse-walk, or circle in which he moves, be large enough in diameter, otherwise he cannot exert all his strength: for in a small circle, the tangent in which he draws, deviates more from the circle in which he is obliged to go than in a larger circle. The diameter of the horse-walk should never, if possible, be less than forty feet. In a walk of nineteen feet, it has been calculated that a horse loses two-fifths of his strength.

A horse exerts his force to the greatest disadvantage in drawing or carrying up a hill. The human form is so much better adapted for climbing than that of a horse, that if the hill be steep, three men will do more than a horse; each man, loaded with 100 pounds, will move up faster than a horse that is loaded with 300 pounds. But one horse can give motion to the horizontal beam in a walk of forty feet, with as much ease as five men; in a walk of nineteen feet, three men would exert themselves with as much effect as a horse.

Of Mill Work.

The term mill, originally signified a machine for grinding corn; but at present the expression mill-work is frequently applied to all kinds of machinery where large wheels are employed.

Mills are distinguished into various kinds, either according to the powers by which they are moved, or the uses to which they are applied; hence we have *water-mills, horse-mills,* and *wind-mills; corn-mills, fulling-mills, powder-mills, boring-mills,* &c. These appellations, indefinite as they are, answer the purpose of common conversation; but it is evident, that a mill is not completely named, unless its use as well as its motive force, is designated.

In ancient times, corn was ground only by hand-mills, consisting of two stones, similar to those used in water-mills, but much smaller, the lower one being fixed, and the upper one having a piece of wood fastened into it to move it by. Machines of this description are still used in India, and also in some sequestered parts of Scotland; in the latter country, they are called *querns;* but in general, wherever large quantities of

grain are to be ground, they have been entirely superseded by mills not moved by manual labour.

In treating of water-mills, which will here be our principal object, we shall have occasion to advert to the most eligible mode of forming the cogs of wheels, and other particulars applicable to machinery in general, and shall conclude with a description of the most simple form of the water corn-mill.

Water-mills are of three kinds, viz. *breast-mills, undershot-mills*, and *overshot-mills*, according to the manner in which the water is applied to the great-wheel. In the first, the water falls down upon the wheel at right angles to the float-boards or buckets placed all round the wheel to receive it. In the second, which is used where there is no fall but a considerable body of water, the stream strikes the float-boards at the lower part of the wheel. In the third, the water is poured over the top, and is received in buckets formed all round the wheel.

It was the opinion of Smeaton, that the powers necessary to produce the same effect on the undershot-wheel, a breast-wheel, and an overshot-wheel, must be to each other as the numbers 2.4, 1.75, and 1.

The effect or momentum of water depending jointly upon its velocity and its quantity, it is of importance to ascertain these particulars; Dr. Desaguliers has given the following easy directions for the purpose: Observe a place where the banks of the river are steep, and nearly parallel, so as to make a kind of trough for the water to run through; then by taking the depth in various parts of the stream's breadth, obtain a correct section of the river. Stretch one line over it at right angles, and another at a small distance above or below, but perfectly parallel. Now throw in some buoyant body (such as an apple, which will not float so high as to be affected by the wind) immediately above the upper line: observe the time it occupies in passing from one to the other string. Thus you ascertain how many feet the current runs in a second, or in a minute. Then having the two sections, that is, one at each line, reduce them to a mean or average depth, and compute the area of the mean section, which being multiplied by the distance between the lines, will give the solid contents of the intermediate volume of fluid, which in the noted time passed from one string to the other. Now this way, by the rule of three, is adapted to any portion of time; the question being merely, if the velocity be such in such an area, or trough, what would be the velocity in another of less size. It is obvious, that if the area give twelve solid feet, and that the water passed at the rate of four feet in a second, through a conduit of one foot square, if the conduit were

only six inches square, the velocity would be as sixteen to four; or in other words, quadrupled.

The arch of a bridge is often an excellent station for observing the force of a stream; because the sides are there regular, and the intermediate space may be correctly measured. But the depth is not always to be ascertained in such places without the aid of a boat, or of two intelligent assistants, who should be very correct in their observations. The arch of a bridge is not a proper station, when the velocity of the current is accelerated for want of sufficient water-way.—For some further remarks on this subject, see page 110, vol. 2.

Practical Rules and Observations relative to the Construction of Water-Mills.

1. Measure the perpendicular height of the fall of water, in feet, above that part of the wheel on which the water begins to act, and call that the height of the fall.

2. Multiply this constant number 64.2822 by the height of the fall in feet, and the square root of the product will be the velocity of the water at the bottom of the fall, or the number of feet that the water there moves per second.

3. Divide the velocity of the water by three, and the quotient will be the velocity of the float-boards of the wheel, or the number of feet they must each go through in a second, when the water acts upon them so as to have the greatest power to turn the mill.

4. Divide the circumference of the wheel in feet by the velocity of its floats in feet per second, and the quotient will be the number of seconds in which the wheel turns round.

5. By this last number of seconds divide 60, and the quotient will be the number of turns of the wheel in a minute.

6. Divide 120 (the number of revolutions a mill-stone four feet and a half in diameter ought to have in a minute) by the number of turns of the wheel in a minute, and the quotient will be the number of turns the mill-stone ought to have for one turn of the wheel.

7. Then, as the number of turns of the wheel in a minute is to the number of turns of the mill-stone in a minute, so must the number of staves in the trundle be to the number of cogs in the wheel, in the nearest whole numbers that can be found.

By these rules the following table is calculated to a water-wheel eighteen feet in diameter, which size has been found by experience to be the most eligible for general use.

Calculations of mill-work.

The Millwright's Table.

Height of the fall of water.	Velocity of the fall of water per second.		Velocity of the wheel per second.		Revolutions of the wheel per minute.		Revolution of the mill-stone for one of the wheels.		Cogs in the wheel, and staves in the trundle.		Revolutions of the mill-stone per minute by these staves & cogs	
Feet.	Feet.	100th parts of a foot.	Feet.	100th parts of a foot.	Revolutions.	100th parts of a rev.	Revolutions.	100th parts of a rev.	Cogs.	Staves.	Revolutions.	100th parts of a rev.
1	8	02	2	67	2	83	42	40	254	6	119	84
2	11	34	3	78	4	00	30	00	210	7	120	00
3	13	89	4	63	4	91	24	44	196	8	120	28
4	16	04	5	35	5	67	21	16	190	9	119	74
5	17	93	5	98	6	34	18	92	170	9	119	68
6	19	64	6	55	6	94	17	28	156	9	120	20
7	21	21	7	07	7	50	16	00	144	9	120	00
8	22	68	7	56	8	02	14	96	134	9	119	34
9	24	05	8	02	8	51	14	10	140	10	119	14
10	25	35	8	45	8	97	13	38	134	10	120	18
11	26	59	8	86	9	40	12	76	128	10	120	32
12	27	77	9	26	9	82	12	22	122	10	119	80
13	28	91	9	64	10	22	11	74	118	10	120	36
14	30	00	10	00	10	60	11	32	112	10	118	72
15	31	05	10	35	10	99	10	98	110	10	120	96
16	32	07	10	09	11	34	10	58	106	10	120	20
17	33	06	11	02	11	70	10	26	102	10	119	34
18	34	02	11	34	12	02	9	98	100	10	120	20
19	34	95	11	65	12	37	9	70	98	10	121	22
20	35	86	11	95	12	68	9	46	94	10	119	18
1	2		3		4		5		6		7	

To construct a mill by this table, find the height of the fall of water in the first column, and against that height in the sixth column, is given the number of cogs in the wheel and staves in the trundle, for causing a mill-stone four feet six inches in diameter, to make 120 revolutions in a minute as nearly as possible, when the circumference of the wheel moves with one-third part of the velocity of the water. And it appears by the seventh column, that the number of cogs in the wheel, and staves in the trundle, are so nearly adapted to the required purpose, that the least number of revolutions of the

millstone in a minute is 118, and the greatest number exceeds not 121, which is according to the speed of some of the best mills.

It should be observed, that the breadth of the water-wheel ought to correspond with the power necessary on the occasion, supposing that a proportionate volume of water is at command; for a wheel of two feet in breadth will be more than doubly as powerful as one only a foot broad, there being a double volume of water acting upon it, while the friction of the axis is by no means doubled with this augmentation of breadth.

To compute the effects of water-wheels with precision, it is necessary to ascertain, 1. The real velocity of the water which acts upon the wheel; 2. the quantity of water expended in a given time; and 3. how much of the power is lost by friction. After a variety of experiments, Smeaton found that the mean power of a volume of water 15 inches in height gave 8.96 feet of velocity in each minute to a wheel on which it impinged. The computation of the power to produce such an effect, allowing the head of water to be 105.8 inches, gave 264.7 pounds of water descending in one minute through the space of 15 inches; therefore 264.7, multiplied by 15, was equal to 3.970. But as that power will raise no more than 9.375 pounds to the height of 135 inches, it was manifest that the major part of the power was lost; for the multiplication of these two sums only amounted to 1,266; of course the friction was equal to three-fourths of the power. The distinguised Engineer above-mentioned, considers this the maximum single effect of water upon an undershot-wheel, where the fall is fifteen inches. The remainder of power, it is plain, must equal that of the velocity of the wheel itself, multiplied into the weight of the water, which in this case brings the true proportion between the power and the effect to be as 3,849 to 1,266, or as 11 to 4.

Care should be taken to make the float-boards rather numerous than few. Smeaton found, that in undershot-mills, when he reduced the number of floats from twenty-four to twelve, the effect was reduced one-half, because the water escaped between the floats without touching them; but when he added a circular sweep of such length, that before one float-board quitted it, another had entered it, he found the former effect nearly restored. This mode more particularly applies to breast-wheels, or such as receive the water immediately below the level of the axis. In such the circular trough is necessary, to make the water communicate the full effect desirable from the joint operation of velocity and weight. In wheels of this kind, the float-boards should be confined both at their sides and at their extremities, so that the water

may accompany them all the way from the head down to the lowest part of the wheel, whence it should pass off with sufficient readiness to allow the succeeding fall to supply its place, without being in the least retarded. Any quantity of water remaining in the trough, at the bottom of a breast-wheel in particular, must tend to oppose its motion, in the exact ratio with the disposition of the fluid to become stagnant or stationary. It has been ascertained that a very sensible advantage is gained by inclining the float-boards to the radius of the wheel, so that each float-board, when lowest, shall not be vertical, but have its edge turned up the stream about twenty degrees.

The overshot-wheel is by far the most powerful; both because it receives the water at the very commencement of its descent, and because the buckets with which it is ordinarily furnished retain the power so long, the water being gradually discharged, as these buckets successively become inferior parts of the circumference. It may be proper to state, in this place, that much may be effected by allowing the water merely to flow upon the upper part of the wheel, into the superior buckets, whereby an immense auxiliary force is erected as they successively become filled. Add to this, Smeaton's discovery, that "the more slowly any body descends by the force of gravity while acting upon any piece of machinery, the more of that force will be spent upon it, and consequently the effect will be the greater." That effect is by no means increased in proportion to the velocity of the wheel's motion; on the contrary, Smeaton found, that when the wheel with which he experimented, and which was two feet in diameter, revolved 20 times in a minute, its effect was greatest: when it made only 18½ turns, the effect was irregular: and when so laden as not to make 18 turns, the wheel was overpowered by the load. He found that 30 turns in the minute occasioned a loss of about one-twentieth, and that when turned above 30 times in a minute, the diminution of effect was nearly one-fourth of its powers. This proportion may be easily estimated on any wheel of greater extent, by computing the proportion of accumulated power lost by greater velocity than may be sufficient to load the wheel by means of the buckets being filled; observing that the progress of a machine may be so much retarded as to cause the effect to be irrelevant of the purpose, although the machine may be kept in motion. Some machines do their work well, simply in consequence of a certain celerity, as is generally the case in a grinding apparatus: and every person conversant in the practice of agriculture is aware, that when a plough is drawn at a certain pace, it will cut the soil

regularly and freely, while, on the other hand, the same cattle proceeding at a very slow pace will be more fatigued though they do less work, and that diminished quantity of work by no means so neatly executed.

The breast-wheel, when well constructed, will carry an effect equal to half or even three-fifths of the power, while the overshot-wheel will work with a result equal to four-fifths of the power; yet in general, from inattention to the lessening of friction, and other imperfections of construction, the overshot-wheel does not perhaps perform work beyond half the power, and the effect of the breast-wheel, from similar causes, is proportionately reduced.

When the stream would supply too much water, the redundancy can in general be easily carried off by sluices or overflows, constructed for the purpose; and when it is desirable to increase the velocity of the usual current, much may be done towards the complete attainment of this object, by contracting the banks. It is also very obvious, that by giving additional height to the fall, or head, whence the water flows upon the wheel, velocity, or at least power, may be greatly augmented.

In situations where the supply of water, though often superabundant, is at other times liable to be greatly deficient, the propriety of forming a suitable reservoir, from which the supply may be derived in seasons of drought, deserves to be considered. In some cases, the expense of carrying such a plan into execution, would doubtless exceed any advantage it would produce: but in others it might be adopted with the happiest success; for it will certainly be understood, that such a reservoir is not necessarily required to be near the mill, but at any part of the course of the stream where the cheapness of the land combines with its suitableness in other respects for the purpose.

Attempts have been made to construct water-wheels which receive the impulse obliquely, like the sails of a common windmill. By this means a slow but deep river could be made to drive our mills; though much power would be lost by the obliquity. Dr. Robinson describes one that was very powerful; it was a long cylindrical frame, having a plate standing out from it about a foot broad, and surrounding it with a very oblique spiral like a cork-screw. This was immersed nearly a quarter of its diameter, (which was twelve feet,) having its axis in the direction of the stream. By the work performed, it seemed more powerful than a common wheel that occupied the same breadth of the river. Its length was not less than twenty feet; had it been twice as long, it would have nearly

doubled its power, without occupying more of the water-way. Perhaps such a spiral continued quite to the axis, and moving in a suitable canal, wholly filled by the stream, might be an advantageous way of employing a deep and sluggish current.

Emerson observes, that the teeth of wheels ought not to act upon each other before they arrive at the line which joins their centres; and though the inner or under sides of the teeth may be of any form, yet it is better to make both sides alike, that the wheels may admit of being revolved either way with equal facility. The utility of making the teeth as fine as the case admits, so that the greatest number possible may be in contact at once, has already been insisted on; and the utmost care should be taken to have them so regularly disposed that they may not interfere with each other before they begin to work.

It is of the greatest consequence to have the teeth so formed, that the pressure by which one of them urges the other round its axis, may be constantly the same. This is by no means the case, when the common construction of a spur-wheel, acting in the cylindrical staves of a lantern or trundle, is used. The ends of teeth should never be formed of parts of circles, unless working with other teeth specifically adapted to them, as will be more fully explained hereafter.

The wheels and pinions of the best clock and watch-work, are made true with almost mathematical precision; but in treating of the endless screw, we have had occasion to notice that many great impediments combine to prevent very large wheels, either in wood or metal, from possessing that absolute correctness of form which is so much to be desired. In consequence, the trundle seldom divides the wheel so exactly, as to make a given number of revolutions for one of the wheel without a fraction; but as any exact number is not necessary in mill-work, and the cogs and rounds cannot be set in so truly as to make all the intervals between them precisely equal, it is a useful precaution, which skilful mill-wrights seldom fail to adopt, to give the wheel what is called a *hunting-cog;* that is, one cog more than what will answer to an exact division of the wheel by the trundle. This being done, every cog, as it comes to the trundle, will take the next staff or round behind the one which it took in the former revolution; and by this means, the parts of the cogs and rounds which work together, will, in a little time, be worn equally, and to equal distances from one another.

The Method of setting out Wheels.

For a spur-wheel and wallower, draw the pitch lines A 1, B 1, A 2, B 2, (fig. 1, pl. IV.) then divide them into the number of teeth or cogs required, as *a b c*. Divide one of these distances, as *b c*, into seven equal parts, as, 1, 2, 3, 4, 5, 6, 7: allow three parts for the thickness of the cogs, as 1, 2, 3, in the cog *a;* and four for the diameter of the stave of the wallower, as, 1, 2, 3, 4, in the stave *m*, fig. 2. Three parts are allowed for the cog, and four for the stave, because the wallower is supposed to be of less diameter than the wheel, therefore subject to more wear, in proportion as the number of cogs exceed the number of staves; but if in any case the number of staves and cogs be the same, they may be of equal thickness. The height of the cog is equal to four parts; then divide its height into five equal parts, as 1, 2, 3, 4, 5, in the cog *c;* allow three for the bottom to the pitch line of the cog; the other two parts for the curve which must be given it to make it fit and bear on the stave equally.

In common practice, the millwrights are accustomed to put the point of a pair of compasses in the dot 3 of the cog *a*, and strike the line *d e;* then they remove the point of the compasses to the point *d*, and strike the curve 3 *f*, by which means they obtain a curve which they consider sufficiently correct for their purpose.

For a face-wheel, the following method is adopted: divide the pitch line AB, fig. 2, into the number of cogs intended, as *a b c;* divide the distance *b c*, into seven equal parts; three of those parts allow for the thickness of the cogs, as 1, 2, 3, in the cog *a*, four for the height, and four for the width, as *d e*, and four for the thichness of the stave *m*. Draw a line through the centre of the cog, as the line A 1, at S; and on the point 5 describe the line *d e;* remove the compasses to the point A, and draw the line *f g*, by which the shape of the cog will be determined.

For common spur-nuts, divide the pitch-line, A, fig. 3, into twice as many equal parts as there are intended to be teeth, as *a, b, c, d, e;* with a pair of compasses opened to half the distance of any of these divisions, from the points *a* 1, *c* 3, *e* 5, draw the semi-circles *a, c,* and *e*, which will form the ends of the teeth. From the points 2, 4, and 6, draw the semi-circles *g h i*, which will form the lower parts of the spaces. Though spur-nuts are usually set out in this manner, yet it should be remembered, that in all good work, the ends of the teeth must not be semi-circles unless working with other teeth adapted to them, as will be afterwards noticed.

Of Bevel-Geer.

Instead of spur-wheels and trundles, bevelled wheels, more commonly called bevel-geer, are now generally used. Wheels of this class, it may be shewn, are, in effect, truncated cones, rolling on the surface of each other. Suppose the cones A and B, revolving on their centres *a p*, *a c*, fig. 4, pl. IV; if their bases are equal, they will perform their revolutions in equal times, and consequently any two points equally distant from the centre *a* of A, as *a b*, *a c*, *a d*, *a e*, will revolve in the same time as *a f*, *a g*, *a h*, *a i*. In like manner, if one of the cones, as in fig. 5, be twice the diameter of the other at the base, and they are turned upon their centres, the base of the larger will only have made one revolution, while that of the smaller will have made two revolutions; and all the corresponding parts of the conical surfaces will observe the same proportion; that is, *a b*, *a c*, *a d*, *a e*, will turn only once round, while *a f*, *a g*, *a h*, *a i*, turn twice round. Hence it is obvious, that the number of the revolutions of all cones revolving in this manner, must be to each other as their respective diameters. Now let two cones have teeth cut in them; as represented by fig. 6; they will then become *bevel-geer*. The teeth in an entire cone would be broadest at the base, from whence they would gradually taper with the lessening circumference of the cone, till they terminated at the apex or centre *a* in a point; but as such an extent of teeth would be unnecessary, and if the cones were entire the axes at *a* would incommode each other, the slender useless part of the teeth are cut off, as at E and F; or rather, bevel-geer is composed of wheels made in the form of truncated cones, as shewn by fig. 7, where the upright shaft or axle, AB, with the bevel-wheel CD, turns the bevel-wheel EF, with its shaft GH, and the teeth work freely in each other. The teeth may be made of any dimensions, according to the strength required; and this method will enable them to overcome a greater resistance, and work much more smoothly than a common face-wheel and trundle; besides, the facility with which it enables us to change the direction of a motion, is of great importance.

The method of conveying motion in any direction, and of proportioning or shaping the wheels accordingly, is as follows: let the line *a b*, fig. 8, represent a shaft coming from a wheel; draw the line *c d* to intersect the line *a b*, in the direction intended for the motion to be conveyed, and this line *c d* will represent the shaft of the bevel-wheel which is to receive the

motion. Suppose then the shaft *c d* is to revolve three times, whilst the shaft *a b* revolves once; draw the parallel line *i i* at any moderate distance (suppose one foot by a scale,) then draw the parallel line *k k*, at three feet distance, after which draw the dotted line *w x*, through the intersection of the shafts *a b* and *c d*, and likewise through the intersection of the parallel lines *i i* and *k k*, in the points *x* and *y*, which will be the pitch-line of the two bevel-wheels, or the line where the teeth of the two wheels act on each other, as may be seen by fig. 9, where it is obvious to inspection that the motion may be conveyed in any direction.

Of Hooke's Universal Joint.

The contrivance called the universal joint, which was invented by Dr. Hooke, may be applied to communicate motion instead of bevel-geer, where the velocity is not to be changed, and where the angle does not exceed 30 or 40 degrees. This joint may be constructed as represented by fig. 10; or with four pins fastened at right angles upon the circumference of a hoop, or solid ball. It is useful in cotton-mills, where the tumbling shafts are continued to a great distance from the moving power, as the use of it allows the convenience of cutting them into convenient lengths. It is most proper, when the irregularity of its motion, as it recedes from a right line, is not disadvantageous.

Of the Cycloid and Epicycloid, and the formation of the Teeth of Wheels.

If on the plane CD, fig. 11, a circle B, proceeds in a right line, and at the same time revolves round its centre, till every part of the circumference has touched the plane, a point or pencil, at *a*, which was lowest at the commencement of the motion, will have described the curve CED, which is called a *cycloid*, and is evidently compounded of a rectilinear and circular motion.

If a circle A, fig. 12, roll from *o* to *q*, on the *convex* circumference of another circle B, the point *o* will describe the curve *o p q*, which is called an *exterior epicycloid;* and if the circle A were to roll on the concave circumference of the circle B, as from *r* to *s*, the point *r* would describe an *interior epicycloid.*— In all these cases, the circle by which the curve is obtained, is called the generating circle.

The teeth of wheels and leaves of pinions require great care and judgment in their formation, that they may neither clog the machinery by unnecessary friction, nor act so irregu-

larly as to produce any inequalities in the motion, and the wearing of one part before another. It has long been known that one wheel will not drive another with uniform velocity, unless the teeth of one or more of the wheels have their acting surfaces formed into a curve generated after the manner of an epicycloid. But in order to ensure a uniformity of pressure and velocity in the action of one wheel upon another, it is not absolutely necessary that the teeth of one or both wheels be exactly epicycloids; for if the teeth of one of them be either circular or triangular, with plain sides, or like a triangle with its sides converging to the centre of the wheel, or of any other form, this uniformity of force and motion will be attained, provided that the teeth of the other wheel have a figure which is compounded of that of an epicycloid, and the figure of the teeth of the first wheel. De la Hire has shewn, in a variety of cases, how to find this compound curve; but as it is often difficult to describe, or even to discover its nature, we shall select such forms for the teeth, as are better adapted to practice. There are three different ways in which the teeth of wheels may act upon one another; and each mode of action requires a different form for the teeth:

1st. When the teeth of the wheel begin to act upon the leaves of the pinion just as they arrive at the line of centres; and their mutual action is carried on after they have passed this line.

2nd. When the teeth of the wheel begin to act upon the leaves of the pinion, before they arrive at the line of centres, and conduct them either to this line or a very little beyond it.

3rd. When the teeth of the wheel begin to act upon the leaves of the pinion, before they arrive at the line of centres, and continue to act after they have passed that line.

When the first mode of action is adopted, the acting faces of the leaves of the pinion should be parts of an *interior epicycloid,* generated by a circle of any diameter rolling upon the concave superficies of the pinion; and the acting surfaces of the teeth of the wheel should be portions of an *exterior epicycloid,* formed by the same generating circle rolling upon the convex superficies of the wheel. Now it is demonstrable, that when one circle rolls within another whose diameter is double that of the rolling circle, the line generated by any point of the latter will be a straight line tending to the centre of the larger circle. If the generating circle, therefore, mentioned above, should be taken with its diameter equal to the radius of the

pinion, and be made to roll upon the concave superficies of the pinion, it will generate a straight line tending to the pinion's centre, which will be the form of the acting faces of its leaves; and the teeth of the wheel will in this case be exterior epicycloids, formed by a generating circle, whose diameter is equal to the radius of the pinion, rolling upon the convex superficies of the wheel. This construction of the teeth of the wheel, and leaves of the pinion, is represented by fig. 13, pl. IV; it is strongly recommended by De la Hire and Camus, and is perhaps the most advantageous, as it requires less trouble, and may be executed with greater accuracy than if the leaves of the pinion had been curved as well as the teeth of the wheel.

Lanterns or trundles, which consist of cylindrical staves fixed by both ends nearly at the circumferences of two equal circular boards, and which are so frequently substituted by millwrights for pinions, may often be adopted with great propriety, provided the teeth of the wheels working in them, have a proper form. The construction pointed out by Dr. Brewster, which we shall here present to the reader, possesses the merit of greatly diminishing the friction arising from the mutual action of the staves and the teeth, and of being easily reduced to practice.

Let A, fig. 14, pl. IV, be the centre of the small wheel or trundle, TCHQ, whose teeth are circular like ICR, having their centres in the circle PDEY. Upon B, the centre of the large wheel, at the distances BC, BD, describe the circles FCK, GDO; and with PDEY, as a generating circle, form the exterior epicycloid DNM, by rolling it upon the convex superficies of the circle GDO. The epicycloid DNM thus formed, would have been the proper form for the teeth of the large wheel GDO, had the circular teeth of the small wheel been infinitely small; but as their diameter must be considerable, the teeth of the wheel should have another form. In order to determine their proper figure, divide the epicycloid DNM into a number of equal parts, 1, 2, 3, 4, &c. as shewn in the figure, and let these divisions be as numerous as possible. Then, upon the points 1, 2, 3, &c. as centres, with the distance DC equal to the radius of the circular tooth, describe portions of circles similar to those in the figure; and the curve OPT, which touches these circles, and is parallel to the epicycloid DNM, will be the proper form for the teeth of the large wheel.

In order that the teeth may not act upon each other till they reach the line of centres AB, the curve OP should not touch the circular tooth ICR till the point O has arrived at D. The tooth OP, therefore will commence its action upon the circu-

lar tooth at the point I, where it is cut by the circle DRE. On this account, the part ICR of the cylindrical pin being superfluous, may be cut off, and the staves of the trundle will then be segments of circles similar to the shaded part of the figure.

If the teeth of wheels and the leaves of pinions consisted of materials perfectly hard, and were accurately formed according to these directions, they would act on each other not only with uniform force, but also without friction; because the surfaces in contact would roll upon each other, and neither slide nor rub so as to occasion any imperfection in the performance. But as it is impossible in practice to attain the perfection which theory requires, a certain quantity of friction will remain after every precaution has been taken in the formation of the communicating parts. This friction may be removed, or at least greatly diminished, with respect to a trundle, in the following manner.

If instead of fixing the staves as in the customary manner, at the top and bottom, they are made capable of receiving a rotary motion in their frame, all the friction will be taken away except that which arises from the motion of the cylindrical tooth upon its axis. The advantages attending this mode of construction are very important. The cylindrical staves or teeth may be formed in the lathe with the greatest accuracy; the curve required for the teeth of the large wheel is easily traced; the pressure and motion of the wheels will be uniform; and the teeth are very little subject to wear, because whatever friction remains is almost wholly removed by the revolution of the cylindrical spokes about their axis. This improvement, however, can only be adopted where the machinery is large; for small works, the acting faces of the leaves of the pinion or small wheel should be rectilinear, and those of the large wheel epicycloidal, as exemplified by fig. 13.

We have now to consider the second mode of the mutual action of wheels and pinions, viz. "when the teeth of the wheel begin to act upon the leaves of the pinion, before they arrive at the line of centres, and conduct them either to this line or a very little beyond it." This mode of action is by no means so advantageous as the former, and therefore should, if possible, be always avoided. It is evident, that when the tooth of the wheel acts upon the leaf of the pinion before they arrive at the line of centres, and quits the leaf when they reach this line, that the tooth works deeper and deeper between the leaves of the pinion the nearer it comes to the line of centres; hence a considerable quantity of friction arises, because the tooth does not, as before, *roll* upon the leaf, but *slides* upon it; and from

the same cause, the pinion soon becomes foul, as the dust which lies upon the acting faces of the wheels is pushed into the hollows between them. One advantage, however, attends this mode of action, for it allows us to make the teeth of the large wheel rectilineal, and thus renders the labour of the mechanic less, and the accuracy of his work greater, than if they had been of a curvilineal form. If the teeth therefore of the wheel are made rectilineal, having their surfaces directed to the wheel's centre, the acting surfaces of the leaves must be epicycloids formed by a generating circle, whose diameter is equal to the sum of the radius of the wheel, added to the depth of one of its teeth, rolling upon the circumference of the pinion. But if the teeth of the wheel and the leaves of the pinion are made curvilineal, the acting surfaces of the teeth of the wheel must be portions of an interior epicycloid formed by any generating circle rolling within the concave superficies of the large circle, and the acting surfaces of the pinion's leaves must be portions of an exterior epicycloid, produced by rolling the same generating circle upon the convex circumference of the pinion.

When the teeth of the large wheel are cylindrical spindles, either fixed or moveable upon their axis, an exterior epicycloid must be formed like DNM, in fig. 14, pl. IV, by a generating circle whose radius is AC, rolling upon the convex circumference FCK; AC being in this case the diameter of the wheel, and FCK the circumference of the pinion. By means of this epicycloid, a curve OPT must be formed as before described, which will be the proper curvature for the acting surfaces of the leaves of the pinion, when the teeth of the wheel are cylindrical. In determining the relative diameter of the wheel and pinion for this mode of action, the radius of the wheel is reckoned from its centre to the extremity of its teeth, and the radius of the pinion from its centre to the bottom of its leaves.

The third mode in which one wheel may drive another, viz. "when the teeth of the wheel begin to act upon the leaves of the pinion before they arrive at the line of centres, and continue to act after they have passed that line," remains to be considered. It is represented by fig. 1, pl. V, and as it is a combination of the two first modes, it partakes both of their advantages and disadvantages. It is evident from the figure, that the portion *e h* of the tooth acts upon the part *b c* of the leaf till they reach the line of centres AB, and that the part *e d* of the tooth acts upon the portion *b a* of the leaf after they have passed that line. It follows, therefore, that the acting parts *e h* and *b c* must be formed according to the directions given for the first mode of action, and that the remaining

parts *e d, b a,* must have that curvature which the second mode of action requires; consequently *e h* should be part of an interior epicycloid formed by any generating circle rolling on the concave circumference of the wheel, and the corresponding part *b c* of the leaf should be part of an exterior epicycloid formed by the same generating circle rolling upon *b* E *o*, the convex circumference of the pinion; the remaining part *e d* of the tooth should be a portion of an exterior epicycloid, formed by any generating circle rolling upon *e* L, the convex superficies of the wheel; and the corresponding part *b a* of the leaf should be part of an interior epicycloid described by the same generating circle rolling along the concave side *b* E *o* of the pinion. But, as in practice, the production of this double curvature of the acting surfaces of the teeth would be exceedingly troublesome to the workman, who would probably never correctly accomplish his object, his labour may be abridged by making *e h* and *b a* radial lines, that is, *e h* a straight line tending to the centre of the wheel B, and *b a* likewise a straight line tending to the centre A, of the pinion.

In the preceding remarks, the form assigned to the teeth has been stated on the supposition that the wheel drives the pinion; but when, on the contrary, the pinion drives the wheel, the form assigned to the teeth of the wheel must be given to the leaves of the pinion, and the shape assigned to the leaves of the pinion must be transferred to the teeth of the wheel.

A still different mode of forming the teeth of wheels has had many advocates, who have considered it well calculated to ensure the uniformity of action so much desired. It consists in making the acting faces of the teeth involutes of the wheel's circumference. Thus, let AB, fig. 2, pl. V, be a portion of the wheel on which the tooth is to be fixed, and let A *p a* be a thread wrapped round its circumference, having a loop-hole at its extremity, *a*. In this loop-hole fix a pin *a*, with which describe the curve or *involute, a b c d e h,* by unwrapping the thread gradually from the circumference A *p m*. The curve thus obtained will be the proper form for the teeth of a wheel whose diameter is AB. It is a form which admits of several teeth acting together, a circumstance attended with the advantage of diminishing the pressure upon any one tooth so much as to make the wheels wear longer and more equally; and it possesses the merit of being more easily understood than the other methods directed to be observed.

This last mode of forming the teeth of wheels, is, however, only a modification of the general principle, and indeed an involute is sometimes reckoned among the exterior epicycloids. The propriety of this will be allowed, when it is considered

that the involute *a b c d*, &c. may be produced by an epicycloidal motion. Thus, let *o n* be a straight ruler, at whose extremity is fixed the pin *n*, and let the point of the pin be placed upon the point *m* of the circle, then by rolling the straight ruler upon the circular base, so that the point in which it touches the circle may move gradually from *m* towards B, the curve *m n* will be generated exactly similar to the involute *a b c*, &c. obtained by the string.

The practical mechanic may wish to have more particular directions for drawing epicycloids, than he can derive from the explanation of these curves at the commencement of the present section. For this purpose then, let him take a piece of plain wood G H, fig. 3, pl. V, and fix upon it another piece of wood E, having its circumference *m b* of the same curvature as the circular base upon which the generating circle AB is to roll. When the generating circle is large, the shaded segment B will be sufficient. In any part of the circumference of this segment, fix a sharp-pointed steel pin *a*, which ought to be tempered, that it may easily make a distinct mark; and it must be driven in sloping, so that the distance of its point from the centre of the circle may be equally exact to its radius. Fasten to the board GH, a piece of thin brass, or copper, or tin-plate, *a b*. Place the segment B in such a position, that the point of the steel pin *a* may be upon the point *b*, and roll the segment towards G, so that the nail *a* may rise gradually, and the point of contact between the two circular segments may advance towards *m;* the curve *a b*, described upon the brass plate, will be an accurate *exterior* epicycloid. Remove, with a file, the part of the brass on the left hand of the epicycloid, and the remaining concave arch *a b* will be a pattern tooth, by means of which all the rest may easily be formed. When an *interior* epicycloid is required, the generating circle must revolve upon a *concave* instead of a *convex* base, as in the present instance. The *cycloid*, which is useful in forming the teeth of *rack-work*, is generated in precisely the same manner, with this difference only, that the base on which the generating circle rolls must be a straight line.

Perhaps no part of the mechanism of mill-work is executed with so little attention to theory as the teeth of wheels. Almost every celebrated millwright has his favourite construction, and it is seldom indeed that the best methods are adopted. Gregory describes one of the many plans in ordinary use, and we shall here recite it; from its being, as he observes, of tolerably easy application, and allowing much strength to the teeth, while it is tolerably free from friction in comparison with other practical methods. Let AB, fig. 4, pl. V, be two spur

wheels of different diameters, of which the cogs are intended to work into each other at half pitch. The dotted circular arcs GH, EF, touching each other between *s* and *d*, are the centre or pitch-lines, from which the teeth are formed. If the teeth of both wheels are iron, as is generally the case in the first motions of works, those teeth are then made nearly both of a size at the pitch-line; but if the teeth of one be wood and the other iron, then the iron ones are made to have less pitch than the wooden ones, because they are then found to wear better. In the figure, both are supposed to be of iron. Suppose the wheels to move from G towards H, and from E towards F, and that the sides of the teeth at *b c*, and *d e*, are in contact; from *b* as a centre, with a radius equal to *b p*, describe the arcs *p d*, *l m*; from *d* as a centre, with the same radius, describe the arcs *h i*, *f g*, *c k*. Thus the same opening of the compasses, and a centre chosen where the wheels are in contact on the pitch-lines, will mark the contour of the upper part of a tooth of one wheel, and the lower part of a corresponding tooth of the other wheel; and by taking several centres on the two pitch-lines, the various teeth may be formed. To prevent the cogs from *bottoming*, as the workmen call it, let the lower part, *r e*, of one tooth be made rather longer than the upper part, *p d*, of the other which is to play into it. The way in which cogs thus constructed will work into one another, may be understood by considering the motion of two of them, *n* and *o* for example: when they first come into contact, they will appear as the curve *x* P *z*; when they arrive at Q, the same sides will appear as in the dotted lines there represented; and when the same arrive at R S, they are in contact on their middle points.

Of Wipers for raising Stampers and Hammers.

The notches which project from the circumference of a wheel or an axle, for the purpose of raising stampers, pounders, or hammers in a vertical direction, and then leaving them to fall by their own weight, are usually called *wipers*, though sometimes denominated *lifting cogs*.

When the wipers are only small cylinders or pins projecting perpendicularly from the surface of a horizontal arbor, the force with which they elevate the stampers, &c. will not act uniformly during the whole time in which they are rising; yet a uniformity of force and velocity is generally desirable, and may always be obtained by assigning a proper form to the communicating parts. On this subject, a few directions for the use of the practical mechanic will take up little room.

Fig. 5 pl. V, represents portions of a stamper for bruising

ore, beating hemp, &c. and of its shaft with lifting cogs. G is the vertical arm of the stamper, sliding, when in actual work, between rollers or in a groove, to keep it steadily in its proper position; *a* is the horizontal arm of the stamper; H part of the axle, on which the wipers or lifting cogs EF are fixed; the dotted lines at A, shew the height to which the horizontal arm *a*, of the stamper, is elevated by each wiper. AB is a line corresponding with the arm of the stamper upon which the wipers first act; CD is the pitch-line of the axis, or the bottom of the curves of the wipers. The curved or acting faces of the wipers are involutes of a circle equal in radius to the axis CD, and obtained as already described in noting its application to the formation of the teeth of wheels, viz. by unwrapping from the circumference of the circle alluded to, a thread or cord *b*, in the loop-hole at the extremity of which is a pencil or marking point, describing the curve as it approaches towards *c*. The arm of the stamper is flat at the part where the wiper acts upon it, and should be placed in a line with the centre of the shaft or axis, at the time the first wiper comes into contact with it.

Fig. 6, pl. V, exhibits the form of the wipers for a forge hammer. The centre *b*, of the cylinder AB, in which the wipers are fixed, the flat part or tail end of the hammer, where acted upon by the wipers, and the centre of the axis *a*, of the hammer, must be in the same right line. The proper curve for the wipers is an exterior epicycloid; formed by rolling upon the circumference of the circle at B, a circle of which the radius is equal to the distance from the centre of the axis *a*, to the extremity of the tail of the hammer.

Description of a Corn-mill.

The following is a description of a corn-mill of the most common sort. AB, fig. 7, pl. V, is the water-wheel, which is generally from eighteen to twenty-four feet in diameter, reckoning from the outermost edge of any float-board at A, to that of the opposite one at B. The water striking on the floats of this wheel, drives it round, and gives motion to the mill. The wheel is fixed upon a very stong axis or shaft C, one end of which rests on D, and the other on E within the mill-house.

On the shaft or axis C, and within the mill-house, is a wheel F, about eight or nine feet in diameter, having cogs all round, which work in the upright staves or rounds of a trundle G. This trundle is fixed upon a strong iron axis, called the spindle, the lower end of which turns in a brass foot fixed at H, in a horizontal beam H, called the bridge-tree; and the upper end of the spindle turns in a wooden bush fixed into the nether

mill-stone, which lies upon beams in the floor I. The top of the spindle above the bush is square, and goes into a square hole in a strong iron cross, *a b c d*, fig. 8, called the rynd; under which, and close to the bush, is a round piece of thick leather upon the spindle, which it turns round at the same time it does the rynd.

The rynd is let into grooves in the under surface of the upper or running mill-stone, which it turns round in the same time that the trundle G is turned round by the cog-wheel F. This mill-stone has a large hole quite through its middle, called the eye of the stone, through which the middle part of the rynd and upper end of the spindle may be seen; whilst the four ends of the rynd lie below the stone in their grooves.

One end of the bridge-tree H, which supports the spindle, rests upon the wall, and the other end is let into a beam, called the brayer, LM. The brayer rests in a mortice at L, and the other end M, hangs by a strong iron rod N, which goes through the floor I, and has a screw and nut on its top at O; by the turning of this nut, the end M of the brayer is raised or depressed at pleasure, and consequently the bridge-tree and the upper mill-stone. By this means the upper mill-stone may be set as close to the under one, or raised as much above it as may be necessary. It will of course be understood, that the nearer the mill-stones are to each other, the finer the corn will be ground; and that, on the contrary, the further they are separated, the coarser it will be.

The upper mill-stone is inclosed in a round box, which nowhere touches it, and is about an inch distant from its edge all round. On the top of this box stands a frame for holding the hopper P, to which is hung the shoe Q, by two lines fastened to the hinder part of it, fixed upon hooks in the hopper, and by one end of the string R fastened to the fore part of it, the other end being twisted round the pin S. By turning this pin one way, the string draws up the shoe closer to the hopper, and so lessens the aperture between them; and as the pin is turned the other way, it lets down the shoe, and enlarges the aperture. If the shoe be drawn up quite to the hopper, no corn can fall from the hopper into the mill; if it be let down a little, some will fall; and the quantity will be more or less, according as the shoe is more or less let down; for the hopper is open at the bottom, and there is a hole at the bottom of the shoe, not directly under the bottom of the hopper, but nearer to the lowest end of the shoe, over the middle or eye of the stone.

In a square hole at the top of the spindle, is put the feeder E, fig. 8. This feeder, as the spindle turns round, jogs the shoe three times in each revolution, and so causes the corn to

run constantly down from the hopper through the shoe, into the eye of the mill-stone, where it falls upon the top of the rynd, and is, by the motion of the rynd, and the leather under it, thrown below the upper stone, and ground between it and the lower one. The rapid motion of the stone, creates a centrifugal tendency in the corn going round with it, by which means it gets farther and farther from the centre, as in a spiral, in every revolution, until it is quite thrown out; and being then ground, it falls through a spout, called the mill-eye, into a trough placed for its reception.

When the mill is fed too fast, the corn bears up the stone, and it is ground too coarse; besides, the mill is apt to get clogged, and to go too slowly. When the corn is scantily supplied, the mill goes too fast, and the stones, by their collision, are apt to strike fire. Both these inconveniences are avoided, by turning the regulating pin S backward or forward, in order to draw up or let down the shoe, as the case is observed by the miller to require.

The heavier the running mill-stone, and the greater the quantity of water falling upon the wheel, the faster will the mill bear to be fed, and consequently the greater the performance of the mill; and, on the contrary, the lighter the stone, and the less the quantity of water, the slower must be the feeding. When the stone is considerably worn, and become light, its weight must either be increased by some artificial addition, or the mill must necessarily be fed slowly; otherwise the stone will be too much borne up by the corn under it, to grind the meal sufficiently fine.

The power necessary to turn a heavy mill-stone, is but very little more than what is necessary to turn a light one; for as the stone is supported upon the spindle of the bridge-tree, and the end of the spindle that turns in the brass foot is but small, the difference arising from the weight produces only an inconsiderable action against the power or force of the water. Besides, a heavy stone affords the same advantage as a heavy fly, that is, it regulates the motion much better than a light one, from its not being liable to such great fluctuations of velocity.

The centrifugal force carrying the corn towards the circumference of the stones, it is obvious that it will be crushed when it comes to a place where the interval between the two mill-stones is less than its thickness; yet, as the upper mill-stone is supported on a point which it can never quit, it may not be considered equally obvious why it should produce a greater effect when it is heavy than when it is light; since, if it were equally distant from the nether mill-stone, it could only be capable of a limited impression. But as experience proves

that the difference actually occurs, it may be proper to state the cause. The spindle of the mill-stone being supported by a horizontal piece of timber, about nine or ten feet long, resting only on both its ends, the upper mill-stone, by the elasticity of this piece, is allowed a vertical motion, and plays up and down; by which movement, the heavier the stones are, the more forcibly is the corn wedged in between them.

In order to cut and grind the corn, both the upper and under mill-stones have channels or furrows cut in them, proceeding obliquely from the centre to the circumference. These furrows, in the direction of their length, are cut slantwise on one side, and perpendicularly on the other, so that each of the ridges which they form has a sharp edge; and in the two stones, these edges pass one another like the edges of a pair of scissars, and so cut the corn, to make it grind the more easily, when it falls upon the furrows. The furrows are cut the same way in both stones, when they lie upon their backs, which makes them run crosswise to each other when the upper stone is inverted by turning its furrowed surface towards that of the lower; for, if the furrows of both stones laid the same way, part of the corn would be driven onward in the lower furrows, and come out from between the stones without being either ground or bruised.

The grinding surface of the under stone is a little convex from the edge to the centre, and that of the upper stone a little concave; and they are farthest from one another in the middle, but approach gradually nearer towards the edges. By this means the corn, at its first entrance between the stones, is only bruised; but as it goes farther on towards the circumference or edge, it is cut smaller and smaller, and at last finely ground, just before it comes out from between them.

When the ridges become blunt and the furrows shallow by wearing, the running stone must be taken up, and both of them may then be drest anew with a chisel and mallet. Every time the stone is taken up, there must be some tallow put round the spindle and upon the bush; this unguent will soon be melted by the heat the spindle acquires from its turning and rubbing against the bush, which it will prevent from taking fire.

The bush must embrace the spindle quite close, to prevent any shake in the motion, which would cause some parts of the stones to grate against each other, whilst the other parts of them would be too far asunder, and by that means spoil the meal. Hence, whenever the spindle has worn the bush, so as to begin to shake in it, the stone must be taken up, and a chisel driven into several parts of the bush; and when it is taken out, wooden wedges must be forced into the holes; by

which means the bush will be made closely to embrace the spindle again all round. In doing this, great care must be taken to drive equal wedges into the bush on opposite sides of the spindle; otherwise it will be thrown out of the perpendicular, and so hinder the upper stone from being set parallel to the under one, which is absolutely necessary for making good work. When any accident of this kind occurs, the perpendicular position of the spindle must be restored, by adjusting the bridge-tree with proper wedges put between it and the brayer.

It often happens, that the rynd is a little wrenched in laying down the upper stone upon it, or is made to sink a little lower on one side of the spindle than on the other; and this will cause one edge of the upper stone to drag all round upon the lower, while the opposite edge will not touch. This is easily rectified, by raising the stone a little with a lever, and putting bits of paper, card, or thin chips, between the rynd and the stone.

We shall mention in this place a very useful and ingenious contrivance, adopted by the American millwrights for raising the ground corn to the cooling boxes, or place from which it is conveyed into the bolting machine. They place a large screw horizontally in the box which receives the flour from the mill-stones. The thread or spiral line of the screw is composed of pieces of wood about two inches broad and three long, fixed into a wooden cylinder seven or eight feet in length, which forms the axis of the screw. When the screw is turned round this axis, it forces the meal from one end of the trough to the other, where it falls into another trough, from which it is raised to the top of the mill-house by means of elevators, a piece of machinery similar to the chain pump. These elevators consist of a chain of buckets, or concave vessels like large tea-cups, fixed at proper distances upon a leathern band, going round two wheels, one of which is placed at the top of the mill-house, and the other at the bottom in the meal-trough. When the wheels are put in motion, the band revolves, and the buckets, dipping into the meal-trough, convey the meal to the upper story, where they discharge their contents. The band of buckets is inclosed in two square boxes, in order to keep them clean, and preserve them from injury. It is obvious how much more complete this contrivance is, than the mode adopted in this country, of putting the meal into sacks, and then raising it up by the common machinery for that purpose.

Of Wheel-carriages.

In considering this subject, it will be proper to advert to the formation of the animal by which wheel-carriages are put in motion. The horse is admirably calculated for draught, and the circumstances enabling him to draw to the greatest advantage are, to a certain extent, so well known to every one at all conversant with mechanics, that it is not less a cause of surprise than of regret, that his valuable properties should still continue to be so much abused as we find them to be. But information spreads slowly among the mass of the people, and it is long in reaching provincial wheelwrights, among whom, as amongst other classes of men, there is a disposition to follow the practice of their forefathers, without inquiring whether they are right or wrong. Much as men are attached to their interest too, the arrogance of dominion, even over a brute, often renders them cruel in opposition to it; and cruelty can never bear the light of reason in her path. When the broad-wheel act was passed, a great outcry was raised against it by those whom it would have benefited, and who, instead of complying with it, perversely rendered its provisions worse than nugatory, by bevelling their wheels. Thus, instead of relieving their horses, they adopted a practice tending to oppress them more than ever. With respect to the position of the line of traction, errors of equal moment are frequently committed, as a little attention will enable any one to perceive, who shall consider for a moment the form of the shoulders of a horse. It is evident (see fig. 9, pl. V,) that, at the place where the neck rises from the chest of the animal, the shoulder-blades form the resting place of his collar or harness into a slope, *a p*. This slope or inclination forms an angle with a perpendicular to the horizon, of about fourteen or fifteen degrees; and therefore the line of traction or draught should form the same angle with the horizon, because he will then pull perpendicularly to the shape of his shoulder, and all parts of that shoulder will be equally pressed by the collar. Besides, in overcoming obstacles, the advantage of this inclined direction is *mechanically* great; the following demonstration of it, taken from Walker's "System of Familiar Philosophy," has not perhaps been improved upon. Call *a*, fig. 10, a wheel, *b* an obstacle, *c* the axle of the wheel, *d* the spoke which at present sustains the weight. A line drawn from the nearest part of the horizontal line of draught *c k* to the fulcrum or obstacle at *e*, will form the acting part of a lever *g e;* and another line *e d* being drawn from the fulcrum *e* to the nearest part of the spoke *d*, will form the resisting part of the same lever. Now as the acting and re-

sisting arms of the lever are of equal lengths, the lever becomes a scale-beam, and a draught in the line *g k* must be equal to the weight of the wheel and all that it sustains, besides the friction; for if *g e d* be a crooked lever, a pull at *g* must be equal to all the weight supported by *d*. But when a horse draws agreeably to the shape of his shoulder, in the line *i h*, the acting part of the lever *h e* is lengthened nearly one-fourth; so that if it would require a pull at *g* equal to four hundred weight, a power applied at *h* will draw the wheel over the obstacle *b* with three hundred weight. To those unacquainted with the principles of mechanics, this truth may be easily proved by an ordinary scale-beam. The horse himself, considered as a lever, has in this inclined draught a manifest advantage over his obstacles, in comparison of a horizontal draught, as may be seen by fig. 9. When the horse is yoked to a post, or has any great obstacle to overcome, he converts himself into a lever, making his hind feet the fulcrum, and the centre of gravity of his body to lean over it, at as great a distance as possible, by thrusting out his hind feet; by this means, acting both by his weight and muscular strength, and lengthening the acting part of the lever *a b*, he overcomes the difficulty more by his weight than by his muscular strength; for the muscles of the fore legs act upon the bones to so great a mechanical disadvantage, that though he exerts them with all his might, they serve, in great efforts, for little more than props to the fore-part of his body. Hence we see the great use of heavy horses for draught. But the great mechanical use and advantage of the inclined line of draught may be more particularly seen, by calling the line *a b*, fig. 9, the acting part of the lever, and the nearest approach from the fulcrum *b* to the inclined line of draught (that is, *b c*) the resisting part of the lever: compare this with the resisting part of a lever touching the horizontal line of draught, (that is, *b d*) and it will be found nearly double; in consequence, agreeably to the known properties of the lever, a weight at *g* would require double the exertion in the horse to remove it, that the same weight would require were it placed at *e*.

From the above data, several important practical conclusions may be drawn;—one is particularly important, that single-horse carts are preferable to teams, because in a team, all but the shaft horse must draw horizontally, and consequently in a manner inconsistent with their structure, and the established laws of mechanics. The small horses of the north of England draw more weight of actual goods than our largest waggon horses, and go longer stages. The small horses of Ireland, as a common load, draw fifteen hundred weight of goods, and travel farther in a day than our waggons, and over worse roads

than ours are in general; ten or twelve hundred weight of real goods is as much as falls to the share of one waggon horse, whose superior strength is wasted upon a cumbrous vehicle, and by the mechanical disadvantages of his draught

Waggon-wheels are generally made with the extremities of the axle inclined downwards; thus is forfeited the advantage of their being formed in a lathe, without more trouble than the makers are inclined to bestow for ordinary purposes; and the ends are seldom, perhaps never, inclined in the same angle or exactly opposite each other, consequently the tendency of the motions of the wheels is in different directions, and the draught of the horses is constantly exerted in twisting them out of their natural course. This mischief is increased by bevelling the wheels, and the horses are harassed to no purpose except that of grinding the roads. Let a bevelled wheel be rolled by itself, it will soon be seen that it will not proceed in a straight line, but in a curved line, like a cone. Sir George Saville, a philosophic patriot, whose memory is illustrious, calculated how far a waggon was rendered a sledge in a journey from London to York. The distance is two hundred miles; thirty of which he found the waggon is drawn as if it were a sledge without wheels. Another disadvantage of a waggon arises from the sluggishness of its motion. This will be readily understood and allowed, when it is considered how small a force will continue the motion of a heavy body, moving with a certain degree of rapidity, in comparison with what is required to impel it from a state of rest; but if the motion of the body be extremely slow, the force necessary to keep it up, must be nearly equal to that which moved it at first. The latter case is precisely that of waggon horses, which have, every instant of their draught, to overcome nearly the whole inertia of their load.

A sledge, in sliding over a plane, suffers a friction equivalent to the distance through which it moves; but if we apply wheels, the circumference of which is eighteen feet, and they turn upon axles, the circumference of which is only six inches, it is plain, that while the carriage moves eighteen feet over the plane, the wheels make but one revolution; and as there is no sliding of parts between the plane and the wheels, but only a mere change of surface, no friction takes place there, the whole being transferred to the nave acting on the axle; so that the only sliding of parts has been betwixt the inside of the nave and the axle, which, if they fit one another exactly, is no more than six inches; hence the friction is reduced in the proportion of six inches to eighteen feet, that is, as thirty-six to one. In all cases, by applying wheels, the friction is

thus lessened, in the proportion of the diameter of the axles to that of the wheels. Another advantage is also gained, by having the surfaces of friction confined to so small an extent, arising from the circumstance of their being more easily made true, kept smooth, and fitted to each other. The only inconvenience is the height of the wheels, which must in most cases be added to that of the carriage itself.

A four-wheeled carriage may be drawn with five times as much ease as one that slides upon the same surface in the condition of a sledge. In four-wheeled carriages, the fore-wheels are made of a less size than the hind ones, in order to enable them to turn in less room; and not for the purpose of bringing into action any supposed pushing quality in high back-wheels.

Large wheels have the advantage over small ones in overcoming obstacles, because wheels act as levers in proportion to their various sizes; but when they are so high as not to allow the line of draught to have the inclination before stated, their advantage as longer levers is counterbalanced by their lessening the intensity of the moving power; therefore the total advantages of wheels drawn horizontally do not increase proportionally to their height.

In ascending, high wheels will be found to facilitate the draught in exact ratio with the squares of their diameters; but in descending, they are liable to press in the same proportion. An admirable device was produced by Lord Somerville, to remedy the latter evil; it consisted in throwing the weight behind the centre in going down hill, by raising the fore part of the body of the cart; so that while the shaft may incline downwards, in proportion to the line of declivity, the bottom of the cart's body should remain horizontal. This construction is now common in Devonshire, and some other counties.

As small wheels turn as much oftener round than large ones as their circumferences are less, so when the carriage is loaded with an equal weight on both axles, the fore axle must sustain as much more friction, and consequently wear out as much sooner than the hind axle, as the fore-wheels are less than the hind ones. This points out that the greatest weight should be laid upon the large wheels; yet it is generally the practice to put the greatest load over the small wheels, which not only makes the friction greatest where it ought to be the least, but also presses the fore-wheels deeper into the ground than the hind-wheels, notwithstanding the former are with more difficulty drawn out of it than the latter. The limitation to loading the hind-wheels with the greatest part of the

weight, will consist in not carrying it to such an excess as to endanger the tilting of the vehicle, in going up-hill

Wheels are commonly made with what is called a dish, that is, the spokes are inserted not at right angles, but with an inclination towards the axis of the nave or centre-piece; so that, if the interior end of the nave were placed on the ground, the spokes being higher at the outside than at their termination in the nave, the wheel appears dished or hollow. Wheels are usually dished about four inches in a diameter of five feet. If the wheels were always to go on smooth and level ground, the best way would certainly be to make the spokes perpendicular to the naves and axles; because they would then bear the load perpendicularly, in which position wood supports the greatest weight. But because roads are generally uneven, one wheel often falls into a cavity, or rut, when the other does not, and then it bears much more than an equal share of the load. Hence the utility of dishing the wheels, because when a dished wheel falls into a rut, the spokes become perpendicular in the rut, and therefore have the greatest strength when the obliquity of the load throws most of its weight upon them; whilst those on the high ground, having less weight to bear, have no occasion, at that time, for their utmost strength. Dished wheels, when on straight or horizontal axles (and no other axles should be used,) have many other excellencies; they make carriages to stand on a broader base, and therefore render them less liable to be overturned; they give more room to the body of the carriage than if the spokes were perpendicular; they stand against side-jolts like an arch, and when the carriage is going along the inclined side of a road, they render it less liable to be overthrown.

If the spokes be set so far from the outer end of the nave, that a perpendicular from the sole to the under side of the axle may fall between an inch and two inches between the bushes, the pressure will be somewhat greater on the outer than on the inward bush, when the wheels are on a level This will be an advantage, particularly when the inner part of the axle-arm is much larger than the outer; as it has then more friction, therefore the pressure should be diminished; besides, every sinking of one wheel more than the other, causes it to pinch the inner bush. It has been proposed, as the best mode of placing the spokes in the naves, to mortise them in two rows, alternately; this does not weaken the centre so much as when all the spokes are in one row or band, and gives a greater power of resistance outwards.

The question whether broad or narrow wheels are best, has been much contested. The popular opinion has always been

in favour of narrow wheels; and accordingly, the carriers thought themselves injured by the broad-wheel act, though it allowed them to draw with more horses, and carry greater loads than usual. This matter deserves a moment's attention. —We have observed on a former occasion, that friction increases somewhat with an increase of surface: so far then, the opinion of the carriers tallies with a general truth; but it is at the same time true, that if the moving body have so thin a resting edge as to cut into the surface over which it passes, the friction will be actually increased by the diminution of the surfaces in contact. It is the want of duly considering this, that supports the prejudice in favour of narrow wheels, which cut and sink into the roads, and may be considered, except on the very few roads that are impervious to them, as constantly going up-hill, even upon level ground. But experience testifies, that instead of thus ploughing the roads, broad cylindrical wheels smooth and harden them, and move with greater facility.

If the tire or iron binding of a wheel be in separate parts, and not in one single hoop, these parts should not be made quite to meet each other at the first; because when the wheel has been some time in use, they will settle more closely to the wheel than they can be laid, and the vacancies will then be filled up. The axle-arm should be a perfect cylinder, or if tapered towards the extremity, the difference of its two diameters should be very trifling; a small degree of taper is preferred by many, because it gives the wheel rather a disposition to slide off, thus preventing it from being apt to close inwardly, and creating excessive friction; but it increases the necessity for good iron washers exteriorly, and of substantial linch-pins. It is not an uncommon practice to *set* the wheels, that is, to give them a slight inclination towards each other, whereby they are, perhaps, an inch nearer at the front than at the back; this is chiefly done to wheels that are bevelled, with a view to make them run more evenly on their sole or bearing part, and to prevent their gaping forward; but it is evidently a distortion, an attempt to rectify one bad thing by another of the same stamp, as if the multiplication of mischief would produce good.

The nave of a heavy wheel, as for an ordinary cart for field purposes, need not be more than twelve or fourteen inches in length; if too short, the wheel will wabble, unless fitted very tightly on the axle; while too long a nave is apt to catch the dirt from the upper part, and to project too much beyond the outer face of the fellies; the length just stated is exclusive of the pan at the outer end.

The proportions of wheels are often regulated as much by the purposes to which the vehicles are applied, as by the facilities they afford to motion; thus waggons have in general large hind-wheels, while in timber-carriages the four are nearly of the same height; the London common stage-carts have large wheels, while the drays used by brewers have very low ones. The reason is obvious: waggons and carts load behind; but drays, and the timber-carriages alluded to, load at the sides; and therefore, for them, large wheels, however much they might favour the draught, would be extremely inconvenient, indeed incompatible with their use. The wheels of single-horse carts for ordinary purposes, where there is no particular necessity for having them low, may be from four feet to four feet six inches in diameter, for a horse of about sixteen hands high. For four-wheeled carriages, suppose four feet to be the height of the fore-wheels, and the line of traction to be drawn at an elevation of fourteen degrees from the centre of its axle, the point where that line cuts the circumference of the wheel in its front, gives that height from the plane on which the carriage stands, that will determine the radius of the hind-wheels.

Wheels, whatever their size, should be made of well-seasoned, tough wood, perfectly free from blemish; the naves are generally of elm, the spokes of oak, and the fellies of elm or of ash. The bent fellies, when the wood has not been hurt by too much heat, have greater strength with less wood, than those which are cut by the saw in a curved direction.

It is common in many places, and deserves to be so everywhere, to have a contrivance for relieving the horse of a loaded cart from the weight pressing on his shoulders, when it is necessary for any purpose to stop awhile; this useful object is attained by an appendage so simple as that of a pole or staff, which, turning on a hook-and-eye hinge, is let down from one of the shafts when the occasion requires.

Clock-Work.

The term *clock-work*, originally imported those wheels, pinions, and other mechanism, which constituted the striking part, or what was formerly called the *clock* part of a movement for measuring time; and that part of the machine which gave motion to the hands for shewing the parts of time, was called the *watch* part. But at present the term watch is appropriated to such movements for measuring time as are carried in the pocket; and the larger movements, whether they strike or not, are called clocks.

Watches which regularly strike the hour, are called *pocket-clocks*: if they only strike the hour, when some particular part for that purpose is touched, they are called *repeating watches*.

The term *chronometer*, is chiefly used by workmen and navigators, to denote a watch or portable machine, constructed with so much care and skill, as to be fit for determining the longitude at sea. The word *time-keeper* is a fit appellation for an astronomical clock, but it is often employed with the same latitude as *time-piece*, which is of more extensive signification, as a general name, or a varied or compendious mode of denoting "any instrument for measuring time."

In treatises, it is usual, for the sake of distinction, to use the terms clock and watch in their ancient sense, generally with the word *part* after them; thus, by the expression *clock part*, is meant the striking portion only, and by that of *watch part*, the going portion only.

There are many documents to prove the existence of clocks, with wheels and weights, in the middle of the fourteenth century; but the invention cannot be traced to an earlier date with any certainty. The sphere of Archimedes, indeed, has been considered as the first attempt towards the formation of a clock; it had a maintaining power, but being without any kind of regulator, could only measure time, as a planetarium exhibits the motion of the stars, with relative, but not positive precision. The opinion of Berthoud, who has investigated the subject with attention, is evidently just, when he asserts that the clock is not the invention of any one man, but an assemblage of successive inventions, each of which is worthy of a separate contriver. 1. Wheelwork, which was known in the time of Archimedes; 2. the application of the weight as a maintaining power; 3. the use of the fly as a regulator; 4. the ratchet wheel and click; 5. the substitution of the balance for the fly, and the escapement which was necessarily introduced at the same time; 6. the application of the dial and hands; and 7. the addition of the striking part.

The introduction of the spiral spring, as a first mover, instead of a weight, took place about the beginning of the sixteenth century. About the year 1650, a new era in the art of clock-work commenced, by the application of the pendulum as a regulator; in the year 1715, a compensation for the effects of change of temperature was applied to time-pieces, which, not long after, were contrived so as to go while they were wound up. From this time, improvements succeeded each other with great rapidity. These improvements relate partly to more accurate workmanship, but principally to the escapement, or different modes of connecting the wheel-work with the pendulum or balance. Volumes would be required to do justice to the persons who have distinguished themselves in this line of art; but we must go little beyond the general

principles of this sort of mechanism, and these will perhaps be best understood, if, in the first place, we describe the parts of a clock.

The profile of the watch or going part of a clock is shewn by fig. 1, pl. VI. P is a weight which keeps the clock going; it is suspended by a catgut band that winds about the cylinder or barrel C, which is fixed upon the axis *a a;* the pivots *b b* go into holes made in the brass plates SS, TT, in which they turn freely. These plates are connected by means of four pillars, only two of which, ZZ, can be seen in the profile, and the whole together is called the frame. On the circumference of barrel C is a spiral groove, in which the catgut lies, and is thereby caused to wind round in a regular manner.

The weight P, if not restrained, would necessarily turn the barrel C, with a uniformly accelerated motion, in the same manner as if the weight was falling freely from a height; but the barrel is furnished with a ratchet-wheel, KK, the right sides of the teeth of which strike against the click, which is fixed with a screw to the wheel DD, so that the action of the weight is communicated to the wheel DD, the teeth of which act upon the leaves of the pinion which turns upon the pivots *c c.* This communication of the teeth of one wheel with another is called pitching. Several things are requisite to form a good pitching, which is very important in all machinery where wheels and pinions are employed; the teeth and pinion leaves should be of a proper shape, and perfectly equal among themselves; the size also of the pinion should be of a just proportion to the wheel.

The wheel EE is fixed upon the axis of the pinion *d;* and the motion communicated to the wheel DD by the weight, is transmitted to the pinion *d,* consequently to the wheel EE, as likewise to the pinion *e,* and wheel FF, which moves the pinion *f,* upon the axis of which, the last or swing wheel GH is fixed. In a word, the motion begun by the weight is transmitted from the wheel GH to the pallets IR of the escapement (fig. 2,) fixed on an arbor going through the back plate of the frame, and carrying a lever XU, (fig. 1,) which is forked at the lower part to receive the pendulum. The pendulum consists of a metallic rod, suspended by a very slender piece of steel spring *y,* from a brass bar A, screwed to the frame of the clock, and has a heavy weight or bob at its lower end. The pendulum *y* B, if once put in motion, will describe round the point of suspension *y,* an arc of a circle, and will continue to go alternately backward and forward till the force impressed upon it is wasted, by the usual causes which tend to destroy all other artificial motions, viz.

friction and gravitation. The pendulum is the time-measurer: at every vibration which it makes, the teeth of the swing-wheel GH act upon the pallets IR, (fig. 2,) in such a manner, that after one tooth H has communicated motion to the pallet R, that tooth escapes; then the opposite tooth G acts upon the pallet I, and escapes in the same manner: and thus each tooth of the wheel escapes the pallets IR, after having communicated their motion to the pallets; so that the pendulum, instead of stopping, continues to move.

The wheel EE, (fig. 1,) revolves in an hour; the pivot *c* of this wheel passes through the plate, and is continued to *r*; upon this pivot is a wheel NN, with a long socket fastened in its centre; upon the extremity of this socket *r* the minute-hand is fixed. The wheel NN acts upon the wheel O; the pinion of which, *p*, acts upon the wheel *gg*, fixed upon a socket which turns along with the wheel N. This wheel *gg*, makes its revolution in twelve hours, and upon the barrel of it is fixed the hour-hand.

From the above description it is easy to see, 1. that the weight P turns all the wheels, and at the same time continues the motion of the pendulum; 2. that the quickness of the motion of the wheels is determined by that of the pendulum; and, 3. that the wheels point out the parts of time divided by the uniform motion of the pendulum. When the catgut upon which the weight is suspended is entirely run down from off the barrel, it is wound up again by means of a key, which goes on the square end of the arbor or axis Q, by turning it in a contrary direction from that in which the weight descends. For this purpose, the inclined side of the teeth of the ratchet-wheel K, (fig. 2,) removes the click C, so that the wheel K turns with the barrel, while the wheel D is at rest; but as soon as the band is wound up, the click falls in between the teeth of the wheel K, and the right side of the teeth again act upon the end of the click, which obliges the wheel D to run along with the barrel, and the spring A keeps the click between the teeth of the ratchet-wheel K. Supposing the wheel DD to turn once round in twelve hours, which it is usually calculated to do in the best time-pieces, then will sixteen turns of the catgut on the barrel C, (fig. 1,) suffice to keep the clock going eight days.

It will now be proper to explain how time is measured by the motion of the pendulum; and how the wheel E, upon the axis of which the minute-hand is fixed, makes but one precise revolution in an hour. The vibrations of a pendulum are performed in a shorter or longer time in proportion to the length of the pendulum itself. A pendulum of 39⅛ inches in length

makes 3600 vibrations in an hour; that is, each vibration is performed in a second of time, and for that reason it is called a *second pendulum.* But a pendulum of $9\frac{25}{32}$ inches makes 7,200 vibrations in an hour, or two vibrations in a second of time, and is called a *half second pendulum.* Hence, in constructing a wheel whose revolution must be performed in a given time, the time of the vibrations of the pendulum which regulate its motion must be considered. Supposing then, that the pendulum *y* B makes 7,200 vibrations in an hour, let us consider how the wheel E shall take up an hour in making one revolution. This entirely depends on the number of teeth in the wheels and pinions. If the swing wheel contains 30 teeth, it will turn once round in the time that the pendulum makes 60 vibrations; for at every turn of the wheel, the same tooth acts once on the pallet I, and once on the pallet K, and at each stroke the pendulum makes a vibration; therefore, as the wheel has 30 teeth, it occasions twice 30 vibrations; consequently this wheel must perform 180 revolutions in an hour; because 60 vibrations, which it occasions at every revolution, are contained 120 times in 7,200, the number of vibrations performed by the pendulum in an hour. Now in order to determine the number of teeth for the wheels EF, and their pinions *e f*, it must be remarked, that one revolution of the wheel E must turn the pinion *e* as many times as the number of teeth in the pinion is contained in the number of teeth in the wheel. Thus, if the wheel E contains 72 teeth, and the pinion *e* contains 6, the pinion will make 12 revolutions in the time that the wheel makes one; for each tooth of the wheel drives forward a tooth of the pinion; and when the 6 teeth of the pinion are moved, a complete revolution is performed; but the wheel E has by that time only advanced 6 teeth, and has still 66 to advance before its revolution is completed, which will occasion 11 more revolutions of the pinion. For the same reason, the wheel F having 60 teeth, and the pinion *f* only 6, the pinion will make the 10 revolutions while the wheel performs one. Now the wheel F being turned by the pinion *e*, makes 12 revolutions for one of the wheel E; and the pinion *f* makes 10 revolutions for one of the wheel F; consequently, the pinion *f* performs 10 times 12, or 120 revolutions in the time the wheel E performs one. But the wheel G, which is turned by the pinion *f*, occasions 60 vibrations in the pendulum each time it turns round; consequently, the wheel G occasions 60 times 120, or 7,200 vibrations of the pendulum while the wheel E performs one revolution; but 7,200 is the number of vibrations made by the pendulum in an hour, and consequently the wheel

E performs but one revolution in an hour; and so of the rest

From this reasoning it is easy to discover how a clock may be made to go for any length of time without being wound up: 1, by increasing the number of teeth in the wheels; 2, by diminishing the number of teeth in the pinions; 3, by increasing the length of the cord that suspends the weight; and lastly, by adding to the number of wheels and pinions: but, in proportion as the time is augmented, the weight must be increased, or the force which it communicates to the last wheel GH will be diminished.

With respect to the watch part of the movement we are considering, it only remains to take notice of the number of teeth in the wheels which turn the hour and minute hands.—The wheel E performs one revolution in an hour; the wheel NN, which is turned by the axis of the wheel E, must likewise make only one revolution in the same time; and the minute hand is fixed to the socket or tube of this wheel, which is fitted pretty tight upon the axis *c* of the wheel E, and being thus carried round only by friction, the hand may be moved round without affecting the wheels between the brass plates. The wheel N has 30 teeth, and acts upon the wheel O, which has likewise 30 teeth, and the same diameter; consequently the wheel O takes an hour to a revolution; now the wheel O carries the pinion *p*, which has six leaves, and which acts upon the wheel *gg* of 72 teeth; consequently the pinion *p* makes 12 revolutions while the wheel *gg* makes one; of course the wheel *gg* takes twelve hours to one revolution, and upon the barrel of this wheel the hour-hand is fixed.

Most of the wheels belonging to the striking part, as well as most of those belonging to the going part, are included between the brass plates SS, TT, seen edgeways in fig. 1; the reason of their being omitted in that figure, is to avoid confusion; but a projection of the whole of the wheels between the plates, as they would be seen if the brass plate SS was removed, is shewn by fig. 2.

Fig. 3. shews so much of the mechanism of the striking part as is contained between the brass plate SS and the dial-plate. The numbers annexed to the different wheels denote the number of teeth they contain.

The striking part now more particularly requires our attention. In fig. 2, *h* is the great wheel of this part, with a barrel and click the same as D; it turns a pinion of eight, on the same arbor with which pinion is the wheel *i*, turning a pinion of eight on the arbor of the wheel *k* of 48 teeth. The

wheel *k* turns another pinion of eight, on the same arbor with the wheel *t* of 48, and this last wheel turns a pinion of 6, on the axis of which is a broad flat piece of metal, called the fly, seen edgeways at *s*. This fly strikes the air with so large a surface, that the resistance it experiences prevents the train of wheels from going too fast. The wheel *i* has eight pins projecting from it; these pins raise the tail of the hammer in succession, as the rotation of the wheel brings them to it; the hammer is returned violently when the pins leave its tail, by a spring *z*, pressing on the end of a pin through its arbor, and strikes the bell *x*: *u* is a short spring which the end of a pin through the arbor touches, just before the hammer strikes the bell, and its use is to lift the hammer off the bell the instant it has struck, that it may not stop the sound. The eighth pin in the wheel *i*, which is called the pin-wheel, must pass by the hammer-tail 78 times in striking the 12 hours; 78 being the number of strokes the bell receives during that time. As the pinion of the wheel *i*, has eight leaves, each leaf of the pinion answers to one of the pins; and as the wheel *h* has 78 teeth, it will turn once in 12 hours, like the great wheel D of the watch part. In the pin-wheel *i*, eight teeth correspond to one of the pins for the hammer, and as the pinion of the wheel *k* has eight teeth, the wheel *k* will turn once for each stroke of the hammer. Then, as the pinion of the wheel *t* turns 6 times for the wheel *k* once, and the pinion of the fly turns 8 times for the wheel *t* once, $6 \times 8 = 48$, the number of turns made by the fly for one stroke of the hammer.

In fig. 3, *r* is a small pinion of one tooth called the gathering pallet; it is fixed on the arbor of the wheel *k*, (fig. 2,) which arbor comes through the brass plate SS (fig. 1,) for the purpose; and consequently, like the wheel *k*, the gathering pallet turns round once for each stroke of the hammer; *s* is a segment of a large wheel, turned by the gathering pallet, and called the rack. The arm *a* is attached to the rack, and the end of it rests against a spiral plate, *v*, called, from its form, the snail. The snail is fixed on the same tubular arbor as the hour-hand and wheel 72, and turns round with it once in 12 hours. Each of the 12 divisions or steps, as they are called, of the snail, answers to an hour; the circular arcs forming their circumference are struck from the centre of the arbor with a different radius, decreasing a certain quantity each time, in the order of the hours; and each step is an arc equal to the twelfth part of the circumference of which it is a part.

The circular part of the rack *s* is cut into teeth, each of which is of such a length that every step upon the snail

answers to one of them. A spring *w* presses against the tail of the rack, and its use is to throw the arm *a* of the rack against the snail. The click *g*, is called the hawk's bill; it takes into the teeth of the rack, and holds it up in opposition to the spring *w*. The three-armed detent, *b k*, is called the warning piece; the arm *k* is bent at its end, and passes through a hole in the plate SS of the frame, so as to catch a pin fixed in one of the arms of the wheel *t*, fig. 2, and which pin describes the dotted circle in fig. 3; the other arm *b*, stands so as to fall in the way of a pin in the wheel O, of 30 teeth. In the present position of the figure, the wheels of the striking train are in motion, and would continue turning until the gathering pallet *r*, which, as before observed, turns once at each stroke of the hammer, lifts the rack *s*, in opposition to the spring *w*, one tooth each turn, and the hawk's bill *g* retains the rack, until a pin in the end of the rack is brought in the way of the lever of the gathering pallet *r*, and stops the wheels from turning any farther: it is in this position, with the rack wound up, that we shall begin to describe the operation of the striking of the clock.—The wheel O, as just observed, turns once in an hour, and consequently at the expiration of every hour, the pin in it takes the end *b*, and moves it towards the spring near it; this depresses the end *k*, until it falls into the circle of the motion of the pin in the wheel *t*, fig. 2, at the same time the short tail depresses one end of the hawk's bill, and raises the other *g*, so as to clear the teeth of the rack *s*; immediately the spring *w* throws the rack back, until the end of its arm *a* rests against the snail. When the rack falls back, the pin in it is moved clear of the gathering pallet *r*, and the wheels are set at liberty; the maintaining power or weight puts them in motion, but in a very short time before the hammer has struck, the pin in the wheel *t* falls against the end *k*, and stops the whole: this operation happens a few minutes before the clock strikes, and the noise of the wheels turning is called the warning. When the hour is expired, the wheel O has turned so far as to allow the end of the arm *b* to slip over its pin, as in the figure; the small spring pressing against it raises the end *k* so as to be within the circle of the pin in the wheel *t*, fig. 2: every obstacle is now removed; the pin-wheel *i*, fig. 2, raises the hammer *p*, and it strikes the bell; the gathering pallet *r* takes up the rack, a tooth at each turn; the hawk's bill *g* retaining it until the pin in the rack comes under the gathering pallet *r*, and stops the motion of the train, till the pin in the wheel O, at the next hour, takes the warning piece *b k*, and the whole operation is repeated.

As the gathering pallet turns once for each blow of the

hammer, and it gathers up one tooth of the rack at each turn, it is evident that the number of teeth the rack can fall back, is the number of strokes the hammer will make. It is obvious also, from the form of the snail, a fresh step of which is turned to the end of the arm *a* of the rack every hour, that the rack must fall back differently each time at the end of that period, and as each step of the snail answers to one tooth of the rack, and each tooth of the rack to one stroke of the hammer, the number of strokes is increased, one at a time, from one to twelve.

As nothing affects the position of the snail but the motion of the wheel *g*, upon the axis of which it is affixed, and as the step upon which the arm *a*, fig. 3, of the rack rested, while any given hour was struck, still remains to be the step upon which it rests till the next has arrived; so, if in any part of the interval between the striking of the given hour, and the warning of the next, any contrivance be adopted to move the arm *b* of the detent, as much as it is moved in the regular period by the pin in the wheel O, the hour which was last struck will be struck over again, or, according to the usual expression, the hour will be repeated; and yet all the subsequent hours will be struck with the same precision, as if the mechanism had not been touched. A slender cord, for instance, attached to the arm *b*, will be quite sufficient to effect the purpose, and might be conveyed through the side of the clock to the bedside, by which means a person may easily ascertain, during the night, the last hour which the clock has struck.

It will also probably be understood, that as the snail accompanies the wheel *g*, fig. 1, on the end of the hollow axis of which the hour hand is fixed, and as *g*, through the medium of the pinion *p*, and the wheel O, derives its motion from the wheel N, the hollow axis of which, carrying at *r* the minute hand, fits tightly, but is not immoveably fixed, upon the arbor *c;* so, if the time of the clock be rectified by pushing forward the hands, the clock part will undergo corresponding changes, and strike each hour passed over, although the wheels of the watch part, between the brass plates, are not affected by the operation.

Clocks intended to keep time with the greatest nicety, are generally contrived so as to go while they are wound up. For this purpose, a second larger ratchet-wheel is added on the same arbor with that which admits the clock to be wound up, but with teeth pointing the contrary way; a strong spring, usually the greatest portion of a circle, connects this large ratchet-wheel with the great wheel of the clock which is on the same axis

with it; one end of this spring being attached to the great wheel, and the other end to the large ratchet; and a catch proceeds from the inner face of the back-plate to the teeth of this ratchet, which prevents its moving back when the clock is winding up, and serves as a support for the re-action of the maintaining spring. When the clock is left to the operation of the weight, the small ratchet turns round the large one, and contracts or coils up the spring till it has strength sufficient to impel the great wheel and train; and when the action of the weight is suspended as in winding up, the spring, freed from the contracting power of the weight, expands itself, and forces round the great wheel; its action on the contrary direction on the great ratchet being prevented by the catch before mentioned.

Clocks which have pendulums vibrating half seconds, frequently have a spring instead of a weight for the maintaining power. This spring consists of a long flat piece of steel, coiled up in a spiral form; it is inclosed in a cylindrical box, to which its external extremity is attached, while its internal end is connected with a fixed axis, round which the spring box revolves. As the strength of the spring is greater the more it is coiled up by turning round the box, its action would be unequal in impelling the work of the clock; and to remedy this inconvenience, the fusee wheel, of the same construction as in watches, is adopted. The manner in which the fusee regulates the action of the spring, has been explained in page 310, and illustrated by a figure. If, instead of the barrel C, fig. 1, a fusee wheel or pulley be supposed to be substituted, and the spiral spring, inclosed in its cylindrical barrel, be added immediately below it, with a catgut to connect the fusee and barrel of the spring, a good idea will be obtained of a spring clock, for in other respects the work is the same.

Mode of dividing the Circumferences of Circles.

Very uncommon and odd numbers of teeth are sometimes required for the wheels of astronomical clocks, orreries, &c. such as the plate of no common engine used by clockmakers for cutting the teeth of their wheels, in the common routine of their business, is calculated for: the following directions are given, for the purpose of shewing how to divide a circle into any given odd number of equal parts, so that the number may be laid down upon the dividing plate of a cutting engine.

With respect to the division of a circle into any even number of equal parts, no difficulty can arise; and if this be easy,

the division of any given portion of a circle into any number of equal parts is not less so. A little consideration will shew that this leads us to a solution of our difficulty. There is no odd number, but, if a certain number be subtracted from it, an even number, of easy subdivision, will remain. Supposing the number of equal divisions wanted to be 69, subtract 9, and 60 will remain; then, as every circle is supposed to contain 360 degrees, say, as the desired number of equal parts in the circle, which is 69, is to 360 degrees, so are 9 parts to the corresponding arc of the circle that will contain them; which arc, by the rule of three, will be found to be 46.95. Therefore, by the line of chords on a common scale, or rather with a sector, set off 46.95 (or 46.9) degrees with a pair of compasses, on the circumference of the circle, and divide that arc, or portion of a circle into 9 equal parts, and the rest of the circle into 60; so will the whole be divided into 69 equal parts.

It is obviously not necessary to take off so many parts as nine, in order to leave a convenient number for subdivision; but this advantage attends taking off a considerable number of degrees from a scale, particularly when they are taken from the scale of chords of a common rule, that they are in general less liable to be taken off inaccurately than a few degrees. The following example is proper when the scale intended to be used is a good one: suppose it is required to divide the circumference of a circle into 83 equal parts, subtract 3, and 80 will remain; then, as 83 are to 360 degrees, so, by the rule of proportion, are three parts to 13.01 degrees. The small fraction here brought out may be neglected; therefore, by the line of chords or sector, as before, with a pair of finely pointed compasses, set off 13 degrees on the circumference of the circle; divide the arc thus set off into three parts, and the remainder of the circle into 80, and the work will be done.

Again, suppose it is required to divide a given circle into 365 equal qarts, subtract 5, and 360 will remain; then, as 365 parts are to 360 degrees, so are 5 parts to 4.93 degrees; therefore set off 4.93 (or 4.9) degrees by the scale; divide that space into 5 equal parts, and the rest of the circle into 360; the whole will then be divided into 365, the desired number of equal parts.

Any person accustomed to the use of a pair of compasses, and to the scale or sector, may very easily, by a little practice, take off degrees, and fractional parts of a degree, with great facility by the accuracy of his eye.

A few remarks with respect to the sector, with which a case of mathematical instruments is always furnished, may be

useful to some. The sector is made to fold in the middle, not only that it may lie in a smaller compass, but to solve many problems by means of the references given to various tables and scales that are engraved on both sides of each limb. When opened to its full length, it commonly measures one foot, each inch being numbered and divided into tenths. At the edge is another scale, which divides the foot into ten equal parts, and each tenth part of the foot is again subdivided into ten; thus giving a division of the 12 inches into 100 equal parts. But the first scale which we have to notice as useful in dividing circles, is that next to the inner edges, marked *Pol.* for polygon. By opening the sector to such a width as may admit the radius of any circle to measure exactly from the figure 6 on one limb, to the figure 6 on the other, we at once ascertain the division of that circle's circumference into any number of equal parts, from four to twelve; because from the figure 4 to the opposite figure 4 will give a chord subtending a quadrant of the circle; from 5 to 5 will give the side of a regular pentagon, or divide the circumference of the circle into five parts; from 6 to 6 into six parts; and so on. Two equal lines of chords marked with the letter C, are inclined to each other, and meet at the centre of the joint of the instrument. To set off any number of degrees on the circumference of any circle, the radius of which does not exceed the length of both these lines together, open the sector till the distance between the 60th degree on each scale of chords, is exactly equal to the radius of the circle to be divided; then from 50 to 50 will give an extent of 50 degrees for the same circle; from 30 to 30 an extent of 30 degrees; and so on for any other number.

Of proportioning the Diameters of Wheels and Pinions.

The due proportioning of wheels and pinions is an important object in all kinds of wheel-work, but especially in clock-making, where, unless the respective sizes be properly adjusted, the transmission of the maintaining power, and communication of motion, will be unequable, and the mechanism liable to rapid destruction. The subject has on these accounts engaged much of the attention of writers on clock-work; but practical men are not yet agreed in the observance of any invariable rule. The usual mode of proportioning wheels and pinions, is, first to make both a little too big for the proposed calliper, and then, having rounded all the teeth of the pinion, and a few of the teeth of the wheel, they gradually diminish the latter in the lathe, until, by successive trials in the clock-frame, they are found to act at a proper depth, when placed in the pivot holes previously made. This practice is extremely

objectionable, as it loses much time, and leaves to the discretion of the workman the determination of the very matter in which he is most apt to err; accordingly, he will at different times differ from himself, and almost to a certainty from other workmen. We shall therefore advert to the directions of the best authorities on this subject, any of which may be followed in preference to the common practice, which has so intimate a connection with caprice.

If the teeth were intended to be rounded in a circular shape which is, however, by no means to be recommended, the pitch-line would be considered as at one-half of the breadth of the tooth from the extreme edge; but if they be rounded in an epicycloidal, or, as the workmen call it, the bay-leaf form, Hatton found, by numerous experiments, that the depth, or distance of the pitch-line from the circumference, will generally be three-quarters of the breadth of the tooth in any wheel or pinion; and as the epicycloidal shape is the best for the regular transmission of force and velocity, it is well entitled to be generally adopted in practice. If then we suppose the teeth, and the spaces between them, to be reciprocally equal, which they usually are in clock-work, we shall have the true acting diameter of any wheel or pinion greater than the diameter to the pitch-line, (which is sometimes called the geometrical, and sometimes the primitive diameter,) by $\frac{3}{4}$ of a tooth or space on each side of the centre, or $1\frac{1}{2}$ in the whole diameter. A tooth or space may be called a *measure*, and it is obvious that there must in any wheel be twice as many measures as teeth. These measures of the circumference may be reduced into measures of the diameter by the usual ratio, of 3.1416 : 1, and then, if $1\frac{1}{2}$ be added to such geometrical measures of the diameter, we shall have the proper acting diameter, which may be expressed in inches and parts, when the number of measures in the inch are known. For instance, let a wheel and its pinion, $\frac{8}{96}$, be taken at 12 teeth per inch at the pitch-line; the number of measures of the wheel is twice 96, or 192, each measuring $\frac{1}{24}$th of an inch; then, as 3.1416 : 1 :: 192 : 61.1; therefore, if to the geometrical diameter expressed by 61.1 measures, there be added 1.5, the sum 62.6, or $62\frac{6}{10}$, will be the acting diameter in the same denomination, which are so many 24th parts of an inch; but 62.6÷24, gives 2.6 inches for the full acting diameter of the wheel in question. With respect to the pinion of 8, which has of course 16 similar measures in its circumference, by the same proportion the diameter will be 5.09 measures; to which if 1.5 be added, the acting diameter will be 5.09+1.5=6.59, or with sufficient accuracy $6\frac{6}{10}$, which divided by 24 as before, will

give $\frac{27}{100}$ of an inch or somewhat more than a quarter for the acting diameter of the pinion.

The following table, which may be considered sufficiently accurate for practice, agrees very nearly with the experiments for determining the proper sizes of wheels and pinions, by Berthoud, an author of the first estimation on these subjects. It is calculated on the supposition that the teeth are epicycloidal, and that the circumference is to the diameter as 3 : 1, instead of 3.1416 : 1.

Table of the Practical Sizes of Pinions.

Teeth in the Pinions	Measures of the Wheel for a Diameter of the Pinion.
3	3.5
4	4.1
5	4.8
6	5.5
7	6.1
8	6.8
9	7.5
10	8.1
11	8.8
12	9.5
13	10.1
14	10.8
15	11.5
16	12.1

To state the manner in which this table is constructed, will enable any person to continue it as far as he pleases. It is simply this: multiply the number of the leaves in the pinion by 2, for the measures in the circumference, divide by 3 for the diameter, and add thereto 1½ for the acting size. Thus, suppose the diameter of a pinion of 9 leaves be required: $9 \times 2 = 18$, and $18 \div 3 = 6$, and $6 + 1.5 = 7.5$, or 7½, which last quantity, taken by the callipers across the extreme edge of the wheel, (the teeth of which are supposed to be cut, but not rounded) will be 3½ teeth and 4 spaces, or 4 teeth and 3½ spaces.

Perhaps some mechanists, not acquainted with decimal arithmetic, may wish for still plainer directions. On this account, and to shew the agreement of Berthoud's practical directions with the rule just laid down, we shall recite the method of sizing pinions practised and recommended by him, viz

Sizing of wheels and pinions.

No. of Leaves.	The full or acting Diameter of the Pinion.
4	=two full teeth of the wheel, unrounded, and the space between them.
5	=three teeth rounded from point to point.
6	=three full teeth, unrounded.
7	=three full teeth, and a quarter of a space beyond.
8	=four teeth, rounded from point to point.
9	=somewhat less than four full teeth.
10	=four full teeth.
11,	no measure given.
12	=five full teeth.
13,	no measure given.
14	=six teeth, rounded from point to point.
15	=six full teeth.

It may be proper to observe, that the relative size of a well-proportioned pinion must be somewhat less for a small wheel than for a large one, and also smaller when driven than when it is the driver. Pennington, of Camberwell, the ingenious artist who constructed Mudge's time-piece, adopts the practice of adding $2\frac{1}{2}$ measures of the geometrical diameter to the wheel, and $1\frac{1}{2}$ to the pinion, in watch-work, when the wheel is the driver; and $1\frac{8}{10}$ to each when the pinion is the driver.

When the distance is given between the centres of two wheels, unequal in the number of their teeth, but intended to turn each other, their respective diameters may be determined by the following rule: as the distance between the centres of the wheels is equal to the sum of both their geometrical radii, (that is, their radii to the pitch-lines, or the radii which they would have if they were merely two cylindrical rollers, one of which turned the other,) therefore say, as the sum of the number of teeth in both wheels is to the distânce between their centres, taken in any kind of measure, as feet, inches, or parts of an inch, so is the number of teeth in either of the wheels to the radius or semi-diameter of that wheel, taken in the like measure, from its centre to the pitch-line. Thus, suppose we require two wheels, of such a size that the distance between their centres shall be five inches, and that one of them is to have 75 teeth, and the other 33; the sum of the teeth in them both is 108; therefore, as 108 teeth are to five inches, so are 75 teeth to 3.47 inches; and as 108 are to 5, so is 33 to 1.52 inches; so that from the centre of the wheel of 75 teeth to its pitch-line is 3.47 inches; and from the centre of the wheel of 33 teeth to its pitch-line is 1.52 inches.

With respect to the best forms for the teeth of clock-work, the subject has been discussed at length in treating of Mill-work, and a reference to that article will render any further notice of it here unnecessary, as the same principles are applicable to both large and small machinery. We may also observe, that the sizing of wheels, which was hardly noticed under Mill-work, will be completed by what has now been said with regard to that particular.

Of the Pendulum.

A pendulum is any heavy body so suspended that it may swing backwards and forwards, about some fixed point, by the force of gravity. A body thus suspended necessarily describes an arc, in one half of which it descends, and ascends in the other.

Each swing which a pendulum makes is called a *vibration*, or *oscillation*.

PC, fig. 4, pl. VI, is a pendulum consisting of a body P, attached by a cord PC, which is fastened to and moveable about the point C. If the body P was not retained by the cord, it would descend in the vertical line PL, but as the cord prevents its falling in this manner, it describes the arc PA, which is the segment of a circle of which PC is the radius. The velocity acquired by the body P in falling through the arc PA, has a tendency, when it arrives at the point A, to carry it off in the tangent AD, but the cord continually drawing it towards the centre, it rises and describes the arc AE. Having arrived at E, it will fall back again, and the velocity acquired in thus falling back will carry it towards P; and this backward and forward motion will be continued till it is overcome by the joint effects of the resistance of the air, the friction at the point of suspension, and the force of gravitation, by which the body P is attracted to the centre of the earth, in a direction perpendicular to the horizon. These causes of obstruction lessen the range of the pendulum at each vibration, and therefore inevitably cause it to stop in a longer or shorter time according to their intensity.

The nature of a pendulum consists in the following particulars: 1. The times of the vibrations of a pendulum in very small arches, are all equal. 2. The velocity of the ball or bob, in the lowest point, will be nearly as the length of the chord of the arch which it describes in the descent. 3. The times of vibration in different pendulums, at the same part of the earth, are as the square roots of the times of their vibrations. 4. The time of one vibration is to the time of the descent, through half the length of the pendulum, as the circumference of a circle to its diameter. 5. Whence the length

of a pendulum vibrating seconds, is found to be 39.2 inches nearly; that of a half-second pendulum 9.8 inches; and one for quarter-seconds 2.45 inches. 6. A uniform homogeneous body, BG, fig. 5, as a rod, staff, &c. which is one-third longer than a pendulum, CP, fig. 4, will vibrate in the same time with it. From these properties of the pendulum may be deduced its utility as a regulator of time, for which purpose it far exceeds every contrivance yet discovered.

When pendulums were first applied to clocks, they were made very short; and the arches of the circle being large, the time of vibration through different arches was therefore unequal. To remedy this defect, the pendulum was contrived to vibrate in a cycloid, by suspending it between two cycloidal cheeks. A thread, or some very pliable material, formed the upper part of the pendulum, and folded alternately upon these cheeks. The property of the cycloidal curve is, that a body vibrating in it will describe all its arches, whether great or small, in equal times; the theory is therefore good, but the practical application of it to the motion of the pendulum, is so imperfect, that cycloidal cheeks are entirely disused. In clocks for astronomical purposes, the arc of vibration must be accurately ascertained, and if it be different from that described by the pendulum when the clock keeps time, a correction must be applied to the time shewn by the clock. This correction, expressed in seconds of time, will be equal to the half of three times the difference of the square of the given arc, and of that of the arc described by the pendulum when the clock keeps time, these arcs being expressed in degrees; and so much will the clock gain or lose, according as the first of these arches is less or greater than the second. Thus, if a clock keeps true time when the pendulum vibrates in an arch of 3 degrees, it will lose 10½ seconds daily in an arch of 4 degrees, and 24 seconds in an arch of 5 degrees.

In all that has hitherto been said, the power of gravity has been supposed constantly the same. But this power is not the same in different latitudes; and the length assigned above to the second, half-second, and quarter-second pendulum, is accurately adapted only to the latitude of London. A pendulum, to vibrate seconds at the equator, must be somewhat shorter; for the semi-diameter of the earth's equator is about seventeen miles longer than the polar semi-diameter, consequently the force of gravity is on this account less at the equator than at or towards the poles; and it is further greatly diminished by the centrifugal force, arising from the diurnal motion of the earth being greatest at the equator. The following Table shews the amount of the variations thus arising:

Length of Pendulums to vibrate Seconds at every Fifth Degree of Latitude.

Degrees of Latitude.	Length of Pendulum.	Degrees of Latitude.	Length of Pendulum.	Degrees of Latitude.	Length of Pendulum.
	Inches.		Inches.		Inches.
0	39·027	35	39·084	65	39·168
5	39·029	40	39·097	70	39·177
10	39·032	45	39·111	75	39·185
15	39·036	50	39·126	80	39·191
20	39·044	55	39·142	85	39·195
25	39·057	60	39·158	90	39·197
30	39·070				

To find the length of a pendulum to make any number of vibrations, and *vice versâ:* Call the pendulum making 60 vibrations in a minute, the standard length; then say, as the square of the given number of vibrations is to the square of 60, so is the length of the standard to the length sought. If the length of the pendulum be given, and the number of vibrations it makes in a minute be required; say, as the given length is to the standard length, so is the square of 60, its vibrations in a minute, to the square of the number required; the square root of which will be the number of vibrations made in a minute.

In considering a simple pendulum, or a ball suspended by a string having no sensible weight, the whole weight of the ball is supposed to be collected in its centre of gravity, and the length of the pendulum is measured from the centre of gravity to the point of suspension. But when a pendulum consists of a ball, or any other solid, suspended by a metallic or wooden rod, the length of the pendulum is the distance from the point of suspension to a point in the pendulum called the *centre of oscillation,* which does not exactly coincide with the centre of gravity of the ball. If a rod of iron, or any other substance, were suspended, and made to vibrate, that point in which all its force was collected, and to which, if an obstacle were applied, all its motion would cease, and be received by the obstacle, is called the centre of oscillation. We have shewn that a homogeneous rod or bar, will perform its oscil-

lations in the same time as a pendulum consisting of a ball and a thread, though only two-thirds of its length. Hence a point taken one-third of the length of such a bar from the lower end, is its centre of oscillation.

The greatest inconvenience attending the use of the pendulum, is its being constantly liable to an alteration of its length, from the effects of heat which expands, and of cold which contracts every material of which it can be made. To remedy this inconvenience, the common method is, to continue the rod through and a little below the bob, which will slide upwards or downwards upon it. The lower part of the rod is screwed, and furnished with a nut, upon which the bob rests; consequently, as the nut is screwed upwards or downwards, the bob, and with it the centre of oscillation, is raised or lowered. This contrivance is a very unscientific one, and of little use; accordingly, the title of a compensation for temperature, is given to those inventions alone in which the efficient principle of regulation is contained within themselves, and constantly acting. Of this character, we shall notice two or three; to enlarge further, would exceed our limits.

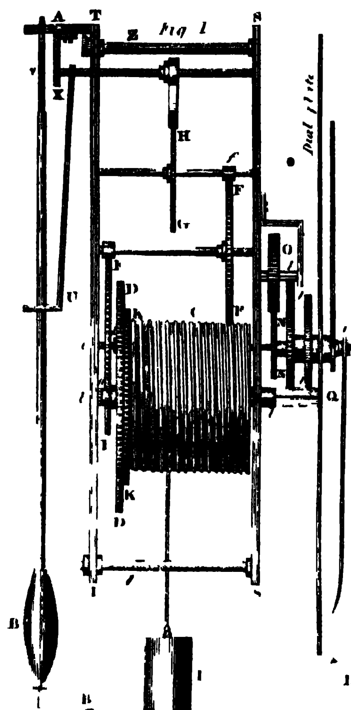
In the year 1721, Graham produced a compensation pendulum, and applied it to a clock, the going of which he compared with one of the best of the common sort, for three years together, and found its errors to be but one-eighth part of those of the latter. The following considerations will explain the principle of this pendulum. If a glass or metallic tube, uniform throughout, filled with quicksilver, and 58.8 inches long, were applied to a clock, it would vibrate seconds, for $39.2 = \frac{2}{3}$ of 58.8, and such a pendulum admits of a twofold expansion and contraction, viz. one of the tube and the other of the mercury, and these will be at the same time contrary, and therefore will correct each other. The tube will extend in length with heat, and so the pendulum will vibrate slower on that account. The mercury also will expand with heat. and since by this expansion it must extend the length of the column upward, and consequently raise the centre of oscillation, so will its distance from the point of suspension be shortened, and therefore the pendulum on this account will vibrate quicker: hence, if the tube and the mercury be skilfully adjusted, the time of the clock will, by this means, for a long course of time, continue the same, without any sensible gain or loss.

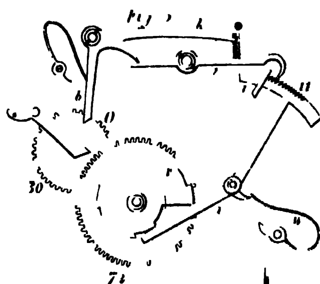
The gridiron pendulum, which has justly obtained a high degree of celebrity, is a contrivance for the same purpose. Instead of one rod, this pendulum is composed of any convenient odd number of rods, as five, seven, or nine, being so con-

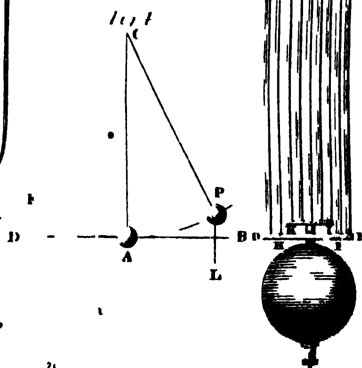
nected, that the effect of one set of them counteracts that of the other set; and therefore, if they are properly adjusted to each other, the centres of suspension and oscillation will always be equidistant. Fig. 6, pl. VI, represents a gridiron pendulum composed of nine rods, steel and brass alternately. The two outer rods, AB, CD, which are of steel, are fastened to the cross pieces, AC, BD, by means of pins. The next two rods, EF, GH, are of brass, and are fastened to the lower bar BD, and to the second upper bar EG. The two following rods are of steel, and are fastened to the cross bars EG and IK. The two rods adjacent to the central rod being of brass, are fastened to the cross pieces IK and LM; and the central rod, to which the ball of the pendulum is attached, is suspended from the cross piece LM, and passes freely through a perforation in each of the cross bars IK, BD. From this disposition of the rods, it is evident that, by the expansion of the extreme rods, the cross piece, BD, and the rods attached to it, will descend; but since these rods are expanded by the same heat, the cross piece, EG, will consequently be raised, and therefore also the two next rods; but because these rods are also expanded, the cross piece IK will descend; and by the expansion of the two next rods, the piece LM will be raised a quantity sufficient to counteract the expansion of the central rod: whence it is obvious, that the effect of the steel rods is to increase the length of the pendulum in hot weather, and to diminish it in cold weather, and that the brass rods have at the same time a contrary effect. The effect of the brass rods must, however, be equivalent not only to that of the steel rods, but also to the part above the frame and spring which connects it with the cock, and to that part between the lower part of the frame and the centre of the ball.

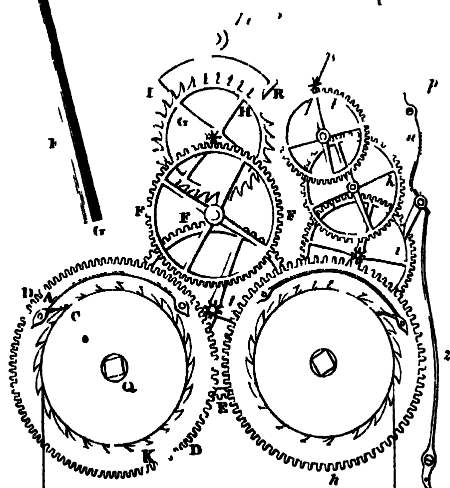
Another useful method of constructing the pendulum is the following: a bar of the same metal with the rod of the pendulum, and of the same dimensions, is placed against the back part of the clock-case; from the top of this a part projects, to which the upper part of the pendulum is connected by two fine pliable chains or silken strings, which just below pass between two plates of brass, whose lower edges will always terminate the length of the pendulum at the upper end. These plates are supported on a pedestal fixed to the back of the case. The bar rests upon an immoveable base at the lower part of the case, and is inserted into a groove, by which means it is always retained in the same position. By this construction, it is intended that the extension or contraction of the bar, and of the rod of the pendulum, shall be equal, and in contrary directions. Thus, suppose the rod of the pendulum to be expanded by any

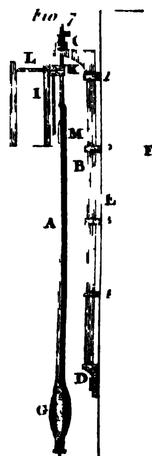
given quantity by heat, and its centre of oscillation consequently tending to a lower point, the bar being at the same time expanded upwards, will, it is presumed, raise the upper end of the pendulum just as much as its length is increased; and hence its length below the plates will be the same as before. Of a pendulum of this sort, somewhat improved by Crosthwaite, a clock and watch-maker of Dublin, we shall insert a further description. AB, fig. 7, pl. VI, are two rods of steel, forged out of the same bar, at the same time, of the same temper, and in every respect similar. On the top of B is formed a gibbet C; this rod is firmly supported by a steel bracket D, fixed on a large piece of marble F, firmly set into a wall, and it has liberty to move freely upwards between cross staples of brass, 1, 2, 3, 4, which touch only in a point in front and rear, (the staples having been carefully formed for that purpose;) to the other rod is firmly fixed by its centre, the lens G, of twenty-four pounds weight, although it should in strictness be a little below it. This pendulum is suspended by a short steel spring on the gibbet at C; all which is entirely independent of the clock. To the back of the clock-plate, I, are firmly screwed two cheeks nearly cycloidal at K, exactly in a line with the centre of the verge L. The maintaining power is applied by a cylindrical steel-stud, in the usual way of regulators, at M. Here the expansion or contraction in either of these exactly similar rods, is counteracted by the other in the manner above mentioned; and this, which has been usually called a compensation pendulum, has been supposed to have an advantage over other compensation pendulums; because the latter being composed of different materials, however just the calculation may seem to be, they will be defective, as not only different metals, but also different bars of the same metal, not manufactured at the same time, and exactly in the same manner, are found by a good pyrometer to differ materially in their degrees of expansion and contraction, a very small change affecting one and not the other. No kind of steel will be so likely to answer well for the two bars in question, as the best cast steel, no other kind possessing nearly so much uniformity of texture. When it is observed that the bars should be of the same temper, it is not to be understood, according to the usual import of the term temper among artists, that they should undergo the regular process of hardening, and then be reduced to a blue or any other colour at discretion; on the contrary, it seems reasonable to suppose, that they can be submitted to no process of preparation so suitable as that of annealing, which will leave them in the softest, but, at the same time, the most uniform state the steel is capable of receiving. They should be annealed alongside of


Fig 1
A
T
S
Z
X
H
F
G
O
U
D
C
N
Q
K
B
I
Dial plate




C
P
D
A
B
L


I
R
H
G
F
C
Q
K
D
E
h
z
p


L
K
I
M
B
A
E
D
G
F

each other, and after undergoing this operation, they should not be hammered. It is, however, to be observed, of the pendulum constructed with these two similar bars, that the bracket D is supposed to be absolutely fixed, whereas it is itself moveable by the expansion and contraction of the block in which it is placed. The pendulum cannot therefore strictly be called a compensation pendulum; but its performance is found to be much superior to that of the common construction.

The most approved mode of diminishing, in a simple pendulum, the errors arising from change of temperature, is to make the rod of straight-grained, well seasoned fir wood, of which the expansion or contraction lengthwise is very small. This wood is best used in its natural state, without baking, varnishing, painting, gilding, or any other preparation, excepting, perhaps, the mere rubbing of it with a waxed cloth. A pendulum also performs better when the ball is heavy, and the arc of vibration small.

In the construction of clocks intended to measure time with the utmost possible exactness, a compensation should also be established for the resistance of the air, which, by its unequal density, varying the weight of the pendulum, must in a small degree accelerate or retard its motion. The celebrated David Rittenhouse, who paid particular attention to this subject, estimates the extreme difference of velocity, arising from this cause, at half a second per day; and he observes, that a remedy dependent on the barometer will not be strictly accurate, as the weight of the entire column of air does not precisely correspond with the density of its base. He proposes, therefore, as a very simple and easy remedy, that the pendulum shall, as usual, consist of an inflexible rod carrying the ball beneath, and continued above the centre of suspension to an equal, (or an unequal) distance upwards. At this extremity is to be fixed another ball of the same dimensions (or greater or less, according as the continuation is shorter or longer,) but made as light as possible. The buoyancy of this upper ball will accelerate its oscillations by the same quantity as those of the lower would be retarded; and thus, by a proper adjustment, the two effects might be made to balance and correct each other. The inventor made a compound pendulum on these principles, of about one foot in its whole length. This pendulum, on many trials, made in the air 57 vibrations in a minute. On immersing the whole in water, it made 59 vibrations in the same time; shewing evidently, that, contrary to what takes place with the common pendulum, its returns were quicker in so dense a medium as water than in air. When the lower bob or pendulum only was plunged in water, it made no more than 44 vibrations in a minute.

ABSTRACT OF MECHANICS;

OR,

A Review of the most important Definitions and Principles of this Division.

The ingenious student will readily perceive the advantage he may derive from being furnished with an epitome like the following, of the different branches of Natural Philosophy, successively treated of. After he has perused the respective dissertations at length, the condensation of the subjects of them thus presented to him, is calculated to save him the trouble of repeated perusal, as a view of the leading principles will often be all that he wants to remind him of the reasoning and facts by which they have been supported and explained.

Of Matter.

1. Every portion of matter is possessed of the following properties, viz. solidity, extension, divisibility, mobility, inertia, attraction, and rèpulsion.

2. *Solidity* is that property by which two bodies cannot occupy the same place at the same time. It is sometimes called the impenetrability of matter.

3. The *extension*, like the solidity of matter, is proved by the impossibility of two bodies co-existing in the same place.

4. *Divisibility* is that property by which bodies are capable of being divided into parts removeable from each other.

5. *Mobility* expresses the capacity of matter to be moved from one position or part of space to another.

6. *Inertia* is the term which designates the passiveness of matter, which, if at rest, will for ever remain in that state until compelled by some cause to move; and on the contrary, if in motion, that motion will not cease, or abate, or change its direction unless the body be resisted.

Space.

1. Space is either absolute or relative:

2. *Absolute space* is merely extension, illimitable, immoveable,

and without parts; yet for the convenience of language it is usually spoken of as if it had parts. Hence the expression,

3. *Relative space,* which signifies that part of absolute space which is occupied by any body, as compared with any part occupied bv another body.

Attraction.

1. Attraction denotes the property which bodies have to approach each other.

2. There are five kinds of attraction,—the attraction of *cohesion,* of *gravitation,* of *electricity,* of *magnetism,* and *chemical attraction.*

3. The attraction of cohesion is exerted only at very small distances.

4. The strength of the attraction of cohesion being different in different kinds of matter, is supposed to be the cause of the relative degrees of hardness of different bodies.

5. Capillary attraction is only a particular modification or branch of the attraction of cohesion.

6. The attraction of gravitation is exerted by every particle of matter on every other particle at all distances, but by no means with equal intensity at all distances.

7. Gravitation decreases from the surface of the earth *upwards* as the square of the distance increases; but from the surface of the earth *downwards,* it decreases only in a direct ratio to the distance from the centre.

Repulsion.

1. Repulsion is that property in bodies, whereby, if they are placed just beyond the sphere of each other's attraction of cohesion, they mutually fly from each other.

2. Oil refuses to mix with water, from the repulsion between the particles of the two substances; and from the same cause, a needle gently laid upon water will swim.

Motion.

1. *Absolute motion* is the actual motion that bodies have, considered independently of each other, and only with regard to the parts of space.

2. *Relative motion* is the degree and direction of the motion of one body, when compared with that of another.

3. *Accelerated motion* is when the velocity continually increases.

4. *Retarded motion* is when the velocity continually decreases; and the motion is said to be *uniformly retarded*, when it decreases equally in equal times.

5. The velocity of uniform motion is estimated by the time employed in moving over a certain space; or, which amounts to the same thing, by the space moved over in a certain time.

6. To ascertain the velocity, divide the space run over by the time.

7. To ascertain the space run over, multiply the velocity by the time.

8. In accelerated motion, the space run over is as the *square* of the time, instead of being directly as the time, as in uniform motion.

9. A body acted upon by only one force, will always move in a straight line.

10. Bodies acted upon by two single impulses, whether equal or unequal, will also describe a right line.

11. But when a body is acted upon by one uniform force, or single impulse, and another accelerating or retarding force, the two forces will cause it to describe a *curve*.

12. The curve described by a body projected from the earth, and drawn down by the action of gravity, would, in an unresisting medium, be that of a parabola; but from the resistance of the air, which, when the velocity is very great, will often amount to one hundred times the weight of the projectile, the curve really described approaches more nearly to that of an hyperbola.

13. The *momentum* of a body is the force with which it moves, and is in proportion to the weight, or quantity of matter, multiplied into its velocity.

14. The actions of bodies on each other are always equal, and exerted in opposite directions; so that any body acting upon another, loses as much force as it communicates.

Central Forces.

1. The central forces are the *centrifugal* and the *centripetal* forces.

2. The centrifugal force is the tendency which bodies that revolve round a centre, have to fly from it in a tangent to the curve they move in, as a stone from a sling.

3. The centripetal force is that which prevents a body from flying off, by impelling it towards the centre, as the attraction of gravitation.

Centre of Gravity.

1. The centre of gravity is that point in a body, about which all its parts exactly balance each other in every position.

2. A vertical line passing through the centre of gravity of a body, is called the *line of direction.*

3. When the line of direction falls within the base of a body, that body cannot descend; but if it fall without the base, the body will fall.

The Lever.

1. There are three kinds of levers, the difference between which is constituted by the difference in the situation of the fulcrum and the power with respect to each other. In the *first* kind of lever, the fulcrum is placed between the power and the weight. In the *second* kind of lever, the fulcrum is at one end, the power at the other, and the weight between them. In the *third* kind of lever, the power is applied between the fulcrum and the weight.

2. In all these levers, the power is to the weight, as the distance of the weight from the fulcrum is to that of the power from the fulcrum.

3. A *bent*, or *hammer lever,* differs only in form from a lever of the first kind.

4. *Scissors, pincers, snuffers,* and the common *iron-crow,* are all levers of the first kind.

5. The *statera* or Roman *steel-yard* is a lever of the first kind, with a moveable weight.

6. A *balance* is also a lever of the first kind with equal arms; a perfect balance should combine the following requisites: 1. The arms of the beam should be exactly equal, both as to weight and length, and should at the same time be as long as possible, relatively to their thickness. 2. The points from which the scales are suspended, should be in a right line, passing through the centre of gravity of the beam. 3. The fulcrum ought to be a little higher than the centre of gravity. 4. The axis of motion should be formed with an edge like a knife, and with the rings and other bearing parts, should be very hard and smooth. 5. The pivots, which form the axis of motion, should be in a straight line, and at right angles to the beam.

7. The best balances are not calculated to determine weights with certainty to more than five places of figures.

8. The oars and rudders of vessels are levers of the second order; a pair of bellows, nut-crackers, &c. are composed of two levers of the same kind

9. The third kind of lever is used as little as possible, on account of the disadvantage to the moving power, the intensity of which must always exceed the resistance; yet in some cases this disadvantage is overbalanced by the quickness of its operations, and the small compass in which it is exerted; hence its fitness for the bones of the arm, and the limbs of animals generally.

10. In compound levers, the power is to the weight, in a ratio compounded of the several ratios which those powers that can sustain the weight by the help of each lever, when used singly and apart from the rest, have to the weight.

The Pulley.

1. Pulleys are of two kinds, *fixed* and *moveable*.

2. The fixed pulley only turns upon its axis, and affords no mechanical advantage; therefore when the power and the weight are equal, they balance each other. It is used for the convenience of changing the direction of a motion.

3. The *moveable* pulley not only turns upon its axis, but rises and falls with the weight.

4. Every moveable pulley may be considered as hanging by two ropes equally stretched, and which consequently bear equal portions of the weight; therefore each pulley of this sort doubles the power.

5. A pulley of one spiral groove upon a truncated cone, as the fusee of a watch, is calculated to maintain a constant equilibrium or relation between two powers, the relative forces of which are continually changing.

Wheel and Axle.

1. The power must be to the weight, in order to produce an equilibrium, as the *circumference* of the wheel is to the *circumference* of the axle.

2. As the diameters of different circles bear the same proportion to each other that their respective circumferences do, the power is also to the weight as the *diameter* of the wheel to the *diameter* of the axle.

3. If one wheel move another of equal circumference, no power will be gained, as they will both move equally fast.

4. But if one wheel move another of different diameter, whether larger or smaller, the velocities with which they move will be inversely as their diameters, circumferences, or number of teeth.

5. The wheel and axle may be considered as a perpetual lever, from the constant renewal of the points of suspension

and resistance. The fulcrum is the centre of the axis, the longer arm is the radius of the wheel, and the shorter arm the radius of the axis.

6. The crane, and many other machines of the first consequence, are composed principally of the wheel and axle.

The Inclined Plane.

1. The power and the weight balance each other, when the former is to the latter as the height of the plane to its length.

2. In estimating the draught of a waggon or other vehicle up-hill, the draught on the level must be added; so that if the hill rises one foot in four, one-fourth part of the weight must be added to the draught on level ground.

The Wedge.

1. When the resistance acts perpendicularly to the sides, that is, when the wedge does not cleave at any distance, there is an equilibrium between the resistance and the power, when the latter is to the former as half the thickness of the back of the wedge is to the length of one of its sides.

2. When the resistance on each side acts parallel to the back, that is, when the wedge cleaves at some distance, the power is to the resistance as the whole length of the back to double its perpendicular height.

3. The thinner the wedge, the greater its power.

4. The further a wedge is driven into any material, the greater also is its power, the sides of the cleft affording it the advantage of operating on two levers.

5. Axes, spades, chisels, needles, knives, and all instruments which begin with edges or points, and grow gradually thicker. act on the principle of the wedge.

The Screw.

1. The screw is an inclined plane encompassing a cylinder.

2. It is generally used with a lever; and the power is to the weight, as the distance from one thread or spiral to another is to the circumference of the circle described by the power.

3. The friction of the screw is very great, a circumstance that occasions this machine to sustain a weight or press upon a body, after the power by which it was impelled is removed.

4. A screw cut on an axle to serve as a pinion, is called an *endless screw.*

5. The endless screw is very useful, either in converting a very rapid motion into a slow one; or *vice versâ,* as for each of its revolutions the wheel moves but one tooth.

Compound Machines.

1. In all machines, simple as well as compound, what is gained in power is lost in time; but the loss of time is compensated by convenience.

2. The mechanical power of an engine may be known by measuring the space described in the same time by the power and the resistance or weight; or by multiplying into each other the several proportions subsisting between the power and the weight, in every simple mechanical power of which it is composed.

3. The power of a machine is not altered by varying the sizes of the wheels, provided this proportion produced by the multiplication of the power of the several parts remains the same.

4. In constructing machines, simplicity of parts and uniformity of motion should be particularly studied.

5. The teeth of wheels should always be made as numerous as possible; and when great strength is required, it should be obtained by increasing the width or thickness of the wheel.

6. The use of the crank is one of the best modes of converting a reciprocating into a rotatory motion, and *vice versâ.*

Fly Wheels.

1. A fly wheel is a *reservoir* of power, and is employed to *equalize* the motion of a machine.

2. This equalization of the motion is the only source of the advantage of a fly, which can impart no power it has not received.

3. When a fly is used merely as a regulator, it should be near the first mover; if intended to accumulate force in the working point, it should not be far separated from that point.

Friction.

1. Friction is occasioned by the roughness and cohesion of bodies.

2. It is in general equal to between one-half and one-fourth of the weight or force with which bodies are pressed together.

3. It is increased in a small degree by an increase of the surfaces in contact.

4. It is increased to an extraordinary degree, by prolonging the time of contact.

5. Two metals of the same kind have more friction than two different metals.

6. Steel and brass are the two metals which have the least friction upon each other.

7. The general rule for lessening friction consists in substituting the rolling for the sliding motion.

Men and Horses, considered as first Movers.

1. In turning a winch, a man exerts his strength in different proportions at different parts of the circle. The greatest force is when he pulls the handle up from the height of his knee; and the least when he thrusts from him horizontally.

2. When two handles are used to an axle, one at each extremity, they should be fixed at right angles to each other.

3. The art of carrying large burdens, consists in keeping the column of the body as directly under the weight and as upright as possible.

4. The horse exerts his force to the greatest disadvantage in drawing or carrying up a hill.

5. The force with which a horse acts is compounded of his weight and muscular strength.

6. The walk of a horse working in a mill, should never be less than forty feet in diameter.

7. A horse exerts most strength when drawing upon a plane.

Mill Work.

1. Water-wheels are of three kinds, viz. *undershot-wheels*, *breast-wheels*, and *overshot-wheels*. The powers necessary to produce the same effect on each of these, must be to each other as the numbers 2.4, 1.75, and 1.

2. The *undershot*-wheel is used only when a fall of water cannot be obtained.

3. A water-wheel twice as broad as another, has more than double the power.

4. An axis furnished with a very oblique spiral, and placed in the direction of a stream, may be rendered a powerful first mover, adapted to a deep and slow current.

5. A mill-stone should make 120 revolutions in a minute.

6. *Bevelled-wheels* are much used for changing the direction of a motion in wheel-work.

7. Hooke's *universal joint* is sometimes used with advantage for the same purpose.

8. The teeth of wheels should never, if it can be avoided, act upon each other before they arrive at the line joining their centres.

9. To ensure a uniformity of pressure and velocity in the action of one wheel upon another, the teeth should be formed into epicycloids; or into involutes of the circumferences of the

respective wheels; or if the teeth of one of the wheels be either circular or triangular, the teeth of the other wheel should have a figure compounded of an epicycloid and that of the figure of the first wheel.

10. The object of thus forming the teeth, is, that they may not *slide* but *roll* upon each other, by which means the friction is almost annihilated.

11. It is a great improvement in machinery, where trundles are employed with cylindrical staves, to make these staves moveable on their axis.

12. A heavy mill-stone requires very little more power than a light one; but it performs much more work, and more effectually equalizes the motion, like a heavy fly.

13. The corn, as it is ground, is thrown out from between the mill-stones by the centrifugal force it has acquired.

14. The manual labour of putting the ground corn into sacks, in order to raise it to the top of the mill-house, may be obviated by the use of a chain of buckets wrought by the machinery.

Wheel Carriages.

1. A horse draws with the greatest advantage, when the line of traction or draught is inclined upwards so as to make an angle of about 15 degrees with the horizontal plane.

2. By this inclination, the line of traction is at right angles to the shape of the horse's shoulders, all parts of which are therefore equally pressed by the collar.

3. Single horses are preferable to teams, because in a team, all but the shaft horse draws horizontally, and consequently to disadvantage.

4. A horse, when part of the weight presses on his back, will draw a weight to which he would otherwise be incompetent.

5. The fore-wheels of carriages are less than the hind-wheels, for the convenience of turning in a smaller compass.

6. In ascending, high wheels facilitate the draught, in proportion to the squares of their diameters; but in descending, they press in the same proportion.

7. In descending, the body of a cart may be advantageously thrown backwards, so that the bottom of it will be horizontal, while the shafts incline downwards.

8. In loading four-wheeled carriages, the greatest weight should be laid upon the large wheels.

9. Dished wheels are better calculated than any other to sustain the jolts and unavoidable inequalities of pressure arising from the roughness of the roads.

10. The extremities of the axles should be in the same horizontal plane, and the wheels should be placed on them at right angles.

11. Broad cylindrical wheels smooth and harden a road, while narrow ones cut it into furrows, and conical ones grind the hardest stones to powder.

Clock-work.

1. To ascertain the number of revolutions which a pinion makes, for one of the wheel working in it, divide the number of its leaves by the number of the teeth of the wheel, and the answer is obtained.

2. By increasing the number of teeth in the wheels; by diminishing the number of leaves in the pinions; by increasing the length of the cord that suspends the weight; and lastly, by adding to the number of wheels and pinions, a clock may be made to go any length of time, as a month, or a year, without winding up.

3. The inconvenience of taking up more room, but principally the increase of friction which would be introduced, are the causes of its being inexpedient to make a clock go much beyond eight days.

4. Clocks intended to keep exact time, are contrived to go whilst winding up.

5. Clocks which have pendulums vibrating half seconds, are frequently moved by a spring instead of a weight.

6. A spring is strongest when it is first wound up, and gradually decreases in strength till the movement stops; it is therefore contrived to draw the chain off a conical barrel, so that the lever at which it pulls is lengthened as it grows weaker, by which means its effects are equalized.

7. The plates of clock-makers' engines, may quickly be divided into odd numbers, by subtracting from the odd number so much as will leave an even number of easy subdivision; then calculating the number of degrees contained in the parts subtracted, and setting them off on the circumference of the circle from a sector.

8. The geometrical radius of wheels, when the teeth are epicycloidal, is less than the acting diameter, by about $\frac{3}{4}$ths of the breadth of a tooth or measure.

9. The relative size of a pinion must be less for a small wheel than for a large one, and also smaller when driven than when it is the driver.

Pendulums.

1. All the vibrations of the same pendulum, whether great or small, if cycloidal, are performed in equal times.

2. The longer a pendulum, the slower are its vibrations.

3. A pendulum to vibrate seconds, must be shorter at the equator than at the poles.

4. Heat lengthens and cold shortens pendulums.

5. The quicksilver pendulum, the gridiron pendulum, and many others, have been contrived to obviate these effects of change of temperature.

6. The vibrations of pendulums are affected by differences in the density of the medium in which they are performed.

7. The merit of the only contrivance to remedy this defect is due to Rittenhouse. It consists in the use of two pendulums, one of which is very light, and placed in an inverted position, extending above the point of suspension of the other.

8. This compound pendulum may be made to vibrate quicker in so dense a medium as water than in the open air.

OPTICS.

THIS branch of Natural Philosophy treats of the mechanical properties of light, and the phenomena of vision.

Many optical appearances are of such frequent recurrence, that they could not escape the notice of the earliest observers; but ages appear to have elapsed, before any progress was made towards an explanation of them. Empedocles was the first person on record, who attempted to write systematically on light. A treatise on optics, attributed to Euclid, who flourished about 400 years before the Christian era, shews the state of knowledge on the subject about that time. It adverts to the effect of bringing into view, by refraction, an object at the bottom of a vessel, by pouring water upon it; but chiefly treats of reflected rays, explaining the effect of different kinds of mirrors, and demonstrating the equality of the angles of incidence and reflection. It appears, also, that the ancients were acquainted with the magnifying power of glass globes filled with water, though they probably knew nothing of the reason of this power; and it is supposed that the ancient engravers used glass globes to magnify their figures, that they might work to more advantage.

Ptolemy, about the middle of the second century, wrote a considerable treatise on optics. The work is now lost, but from the accounts of others, it appears that his observations had even enabled him to treat of astronomical refractions. Alhazen, an Arabian writer, was the next author of consequence; he wrote about the year 1100, and gave the first account of the magnifying power of glasses.

In 1270, Vitellio, a Polander, published a treatise on optics, containing all that was valuable in Alhazen, digested in a better manner, and with clearer explications of various phenomena. He observes, that light is always lost by refraction, which makes objects appear less luminous. He gave a table of the results of his experiments on the refractive powers of air, water, and glass, corresponding to different angles of incidence. He ascribes the twinkling of the stars to the motion of the air in which the light is refracted; and illustrates this hypothesis by observing, that they twinkle still more when viewed in water put in motion. He also asserted, that refraction is necessary as well as reflection, to form the rainbow; because the body which the rays fall upon is a transparent substance, at the surface of which one part of the light is always reflected, and another refracted. He makes some ingenious attempts to

explain refraction, or to ascertain the law of it; and considers the foci of glass spheres, and the apparent size of objects seen through them, though with but little accuracy.

The celebrated Roger Bacon was contemporary with Vitellio, with whose writings, if not also with those of Alhazen, he was probably acquainted. He seems to have acquired the knowledge of some facts, which were unknown to them; yet, with several important truths, he blended, on this subject, much that was wild and fanciful. The invention of the magic lantern is attributed to him; and he demonstrated, by actual experiment, that a small segment of a glass globe would greatly assist the sight of old persons; but concerning the actual inventor of spectacles we have no correct information; this only is certain, that the use of them was generally known about the beginning of the fourteenth century.

In the year 1575, Maurolycus, a teacher of mathematics at Messina, published a treatise on optics, in which he demonstrates that the crystalline humour of the eye is a lens, which collects the rays of light from external objects, and throws them on the retina or back of the eye. From this principle he assigned the reason why some people are short-sighted, and others long-sighted, and why the former are relieved by concave, and the others by convex glasses.

John Baptista Porta, of Naples, was contemporary with Maurolycus. He invented the camera obscura, and his experiments with that instrument convinced him that light is a substance, by the reception of which into the eye, vision is accomplished. This was a great discovery, and corresponds very nearly with the experiments and reasoning of Maurolycus; but it must be remarked, that neither of these two philosophers had any knowledge of what the other had done. The importance of Porta's discovery will be evident, when it is observed, that previous to his time, vision was supposed to be dependent upon what were termed *visual* rays, proceeding from the eye. He justly considered the eye itself as a camera obscura, the pupil performing the office of the hole in the window-shutter; he remarked, also, that a defect of light is remedied by the dilatation of the pupil, which contracts involuntarily when exposed to a strong light, and expands when the light is too faint for distinct vision.

Antonia de Dominis, whose work was published in 1611, was the first who came near the true theory of the rainbow. He describes the progress of the ray of light through each drop of the falling rain; he shews that it enters the upper part of the drop, where it suffers one refraction; that it is reflected once, and then refracted again, so as to come directly to the eye of the

spectator; why this refraction should produce the different colours, was reserved for Sir Isaac Newton to explain.

Telescopes were invented towards the latter end of the sixteenth century. Of this, as of many other memorable discoveries, accident furnished the first hint: Zacharias Jansen, a spectacle maker of Middleburg, trying, it is said, the effects of a concave and convex glass united, found that, if they were placed at a certain distance from each other, they caused distant objects to appear nearer the eye. Other accounts transfer the merit of the first discovery from Jansen himself to his children, who, while playing with spectacle-glasses in his shop, perceived, that when they held two of these glasses between their fingers, at a certain distance from each other, the dial of the clock appeared greatly magnified, but in an inverted position. This incident suggested to their father the idea of adjusting two of these glasses on a board, so as to move them at pleasure. To the Jansens we are also indebted for the discovery of the microscope, an instrument depending upon exactly the same principles as the telescope. Galileo greatly improved the telescope, and constructed one that magnified thirty-three times; with which he made the astronomical discoveries that have immortalized his name.

Kepler paid great attention to the phenomena of light and vision; he was the first who demonstrated that the degree of refraction suffered by light in passing through lenses, corresponds to the diameter of the circle of which the convexity or concavity is the portion of an arch. He very successfully pursued the discoveries of Maurolycus and Porta. The images of external objects, he asserted, were formed upon the optic nerve by the foci of rays coming from every part of the object; and he attributed to habit the power of enabling us to see objects in their right position, though their images upon the retina are inverted. He accounted for the apparent diminution of the moon's disk in solar eclipses by observing, that the disk of the moon does not appear less in consequence of being unenlightened, but that at other times it appears larger than it really is, in consequence of its being enlightened: for pencils of rays from such distant objects generally come to their foci before they reach the retina, which they consequently reach in a state of divergence. Hence he concluded, that different persons may imagine the lunar disk to be of different magnitudes, according to the relative goodness of their sight.

In 1625, the curious discovery of Scheiner was published at Rome, which placed beyond the reach of contradiction, the fact that vision depends upon the images of external objects being depicted upon the retina, and that these images are inverted;

for taking the eye of an animal, and cutting away the coats of the back part, and presenting different objects before it, he displayed their images distinctly painted on the naked retina or optic nerve.

About the middle of the seventeenth century, the velocity of light was discovered by Roemer; and towards the close of it published by James Gregory, the first proposal for a reflecting telescope.

At length arose Sir Isaac Newton, who discovered the cause of colours, an investigation which had eluded the abilities of all the philosophers who had gone before him. He applied his principles to the satisfactory explanation of most of the phenomena of nature where light and colour are concerned; and almost all that we know upon these subjects was laid open by his experiments. He found that the refractive powers of different substances were in general proportionate to their densities, except when they contained inflammable or oily particles. Having proved that the refractive power of diamond was much greater than that of other substances of equal density, he supposed it to contain an inflammable principle,—a happy conjecture, which the modern discoveries in chemistry have irrefragably proved, and which has always been considered a proof of his wonderful sagacity, because it was at complete variance with all that was known in his day respecting the nature of the diamond.

The splendour of Sir Isaac Newton's discoveries obscures in some degree the merit of both earlier and subsequent writers; yet a great variety of interesting facts and improvements have appeared since his time, though it must be admitted that the light by which many of them have been discovered was furnished by his labours. The present admirable mode of constructing reflecting telescopes, to which; after him, many ingenious philosophers and artists have contributed, has led to the most brilliant discoveries; and Dollond's improvement of the refracting telescope has added not a little to the convenience and the value of optical instruments of that description. This artist, by using three glasses, of different refractive powers, was enabled to enlarge the diameters of his object-glasses, and thus to admit more light, and enlarge his field of view, far beyond what the common telescope admitted.

After explaining the principal terms made use of in treating of optics, we shall take a view of the properties of light in general, and then proceed with the particular consideration of refraction, reflection, inflexion, and the phenomena depending upon them.

Definitions.

1. By a *ray* of light is meant the least particle of light that can be either intercepted or separated from the rest. In the diagrams by which the science is illustrated, rays of light are represented by right lines.

2. Any small parcel of rays proceeding from or to a point, considered apart from the rest, is called a *pencil of rays.*

3. A *beam* of light is used to denote any considerable aggregate of light, or parcel of rays.

4. *Parallel rays* are such as move always at the same distance from each other, as represented by fig. 3, pl. I.

5. *Converging rays* are such as approach nearer and nearer to each other, and tend to unite in a point; they are represented by fig. 4, forming a cone, the base of which is at the place where the rays began to converge.

6. *Diverging rays* are those which continue to recede further and further from each other through their whole progress, and if proceeding from a point, form, as shewn by fig. 5, a cone, the base of which is the termination of their course.

7. The point at which converging rays meet, is called the *focus.*

8. When converging rays are prevented from meeting by some obstacle, the point towards which they tend, and where they would have united, if not intercepted, is called the *virtual* or *imaginary focus.*

9. Void space, and whatever substance the rays of light pass through, is called by opticians, a *medium.*

10. Media are either *dense* or *rare:* one medium is said to be more *dense* than another, when it is heavier, or contains more matter under the same bulk; and *vice versâ,* it is called more *rare* than another, when it is lighter, or contains less matter under the same bulk. Glass is more dense than water; water is more dense than air.

11. By a *lens* is meant a transparent body of a different density from the surrounding medium, and terminated by two surfaces, either both curved, or one plane and the other curved. As lenses are commonly made of glass, it is usual to call them *glasses,* with the addition of an epithet, designating their use, or the nature of their curve, or both; as a magnifying-glass, an object or eye-glass of a telescope, a concave spectacle-glass, a convex spectacle-glass.

12. An *incident ray* is that which comes from any body to the reflecting surface; the *reflected ray* is that which is sent back from the reflecting surface. Children sometimes amuse

themselves with presenting a piece of looking-glass to the sun, and casting a vivid spot of light on any object they please. In this case, the rays received directly from the sun are called *incident*, and the lucid spot is made by the *reflected* rays.

13. The *angle* of *incidence* is the angle which is formed by the incident ray with a perpendicular to the reflecting surface at the point of incidence; and the *angle* of *reflection* is the angle formed by the same perpendicular and the reflected ray. Thus, in fig. 6, a ray of light, *a*, falls in the direction *a d*, upon the surface *e f*, and is reflected in the direction *d b; c d* is perpendicular to *e f*, therefore *a d c* is the angle of incidence, and *c d b* is the angle of reflection.

14. A *mirror*, or *speculum*, is an opaque body, the surface of which is very smooth and finely polished, so that it will reflect the rays of light which fall upon it, and by this means represent the images of objects opposed to it.

15. *Plane mirrors* are those reflecting bodies, the surfaces of which are perfectly plane, such as our common looking-glasses.

16. *Concave* and *convex mirrors* are those the surfaces of which are curved. If a watch-glass were silvered on the round side, it would be a concave mirror; if it were silvered on the hollow side, it would be a convex mirror.

Of Light.

The nature of light has been a subject of speculation from the first dawnings of philosophy. Several of the earliest philosophers thought, that objects became visible by means of something proceeding from the eye; while some maintained, that vision was occasioned by particles continually flying off from the surfaces of bodies, which met with others proceeding from the eye; but Pythagoras is said to have ascribed the effect solely to the particles proceeding from external objects, and entering the pupil of the eye. The ancients possessed much greater ingenuity to invent theories, than inclination (or perhaps opportunity) to determine the truth of them by experiment; and therefore, if Pythagoras actually promulgated this opinion, it seems to have been supported by no facts which placed it on an immutable basis. Hence it gained for many ages no greater credit than other opinions, the most incongruous and vague. It was not till about a thousand years after the time of Pythagoras, that J. Baptista Porta fully satisfied himself and others of vision being performed entirely by the intromission of light into the eye.

Several eminent philosophers have imagined, that the sensation which we receive from light is to be attributed entirely to

the vibrations of a subtile medium or fluid, diffused throughout the universe, and put in action by the impulse of the sun. According to this hypothesis, light may be considered as analogous to sound, which is known to depend entirely on the pulsations of the air striking upon the ear. But this theory is encumbered with many difficulties. If light depended altogether upon the vibrations of a fluid, a quick motion of the hand, or of a machine contrived for the purpose, would produce light at any time; or rather, as no solid reason can be assigned why the fluid should cease to vibrate in the night, since the sun must always affect some part of it, we ought to have perpetual day. Again, the texture of certain bodies is actually changed by exposure to light, even though they be inclosed in glass; but if covered with the thinnest plate of metal, which excludes the light, no alteration takes place. Many other objections which militate with equal force against this theory, might be adduced, but these have never received answers which can be deemed satisfactory.

A late writer is decidedly of opinion that light is *diluted fire*, that is, fire weakened and diffused, as ardent spirit when mingled with water. It appears at first view favourable to this opinion, that light may be collected and condensed by the burning-glass, so as to burn like the fiercest flame; on the contrary, flame itself may be attenuated, even by artificial means, to such a degree as to be perfectly innoxious. "The flame," says Dr. Goldsmith, "which hangs over burning spirit of wine, we all know to scorch with great power, yet these flames may be made to shine as bright as ever, yet be perfectly harmless. This is done by placing them over a gentle fire, and leaving them thus to evaporate in a close room without a chimney; if a person should soon after enter with a candle, he will find the whole room filled with innoxious flames. The parts have been too minutely separated, and the fluid, perhaps, has not strength enough to send forth its burning rays with sufficient effect." But when we consider the remarkable discovery of Dr. Herschel, that light may be separated from the caloric* which accompanies it, the identity of the two substances, if not fully disproved, becomes very doubtful. The Doctor, when employed in making observations on the sun by means of telescopes, found that the coloured glasses used to prevent the inconvenience arising from the heat, very soon cracked and broke in pieces when their colour was deep enough to intercept the light. On prosecuting

* *Caloric* is the term by which modern philosophers have agreed to distinguish that peculiar substance which produces heat.

the inquiry, in a course of experiments devised for the purpose, he found that the solar beam contained rays which gave no light, and yet produced a greater degree of heat than even those rays which produced the strongest light. The two species of rays may be separated from each other by a very easy experiment. If a glass mirror be held before the fire, it strongly reflects the rays of light, but the rays of caloric which it sends forth are very few; a metallic mirror, on the other hand, made of planished tin-plate, for example, reflects the rays of light indifferently, but it supplies caloric rays in great abundance. The glass mirror becomes hot; the metallic mirror does not alter its temperature. If a plate of glass be suddenly interposed between a glowing fire and the face, it intercepts completely the warming power of the fire, without causing any sensible diminution of its brilliancy; consequently it intercepts the rays of caloric, but allows the rays of light to pass If the glass be allowed to remain in its station till it becomes as hot as its distance from the fire will allow, it ceases to intercept the rays of caloric, which then pass through it as freely as the rays of light. These data lead us inevitably to the conclusion, that light is not diluted fire or caloric.

We shall now proceed to notice the most important properties of light in an optical point of view;—a task much more delightful than the investigation of its nature and essence; and eminently calculated to entrance the mind with astonishment.

In the very short space of *one second*, a ray of light traverses the prodigious extent of nearly *two hundred thousand miles*. The manner in which the velocity of light is calculated, is not less ingenious than the discovery is surprising. It was by observing the eclipses of Jupiter's satellites, which appeared to be eclipsed sooner or later than the times given by the tables of them, and the observation was always before or after the computed time, according as the earth was nearer to or further from the planet Jupiter than the mean distance. To understand this fact more fully, suppose the earth in going its annual circuit round the sun, is at C, (fig. 1, pl. I,) and that an eclipse is there observed of a satellite of Jupiter, which regularly suffers an eclipse in forty-two hours and a half. If the earth never left C, but continued there immoveable, and Jupiter remained at the same distance, the eclipse of the satellite would always be observable at the expected interval of forty-two hours and a half; and consequently, in thirty times forty-two hours and a half, the spectator would see thirty eclipses. But the earth travelling onward to D, the spectator does not see thirty eclipses till some time after the

stated period, for the further off the earth removes, the longer the time required for the light to reach the spectator. In traversing from C to D, light takes up about sixteen minutes and a half, therefore, as the sun is half way between C and D, it must perform its journey from him in half that time, that is, in eight minutes and a quarter; or, according to the most exact calculation, in eight minutes and seven seconds.* No difference in the velocity of light has ever been discovered, whether it is original, as from the stars, or reflected only, as from the planets.

Such being the rapidity with which the rays of light dart themselves forward, it becomes a matter of easy calculation, and may a little assist our conception to observe, that a journey which they perform in eight minutes, could not be performed by a cannon ball at its ordinary speed in less than thirty-two years. That the motion of light is inexpressibly rapid, we may easily convince ourselves, if we notice the firing of a cannon or a musket at a considerable distance, and observe the time which elapses between seeing the flash and hearing the report. Sound, it has been calculated, travels at the rate of 1142 feet, or 380 yards, in a second; yet the time which intervenes between seeing the flash and hearing the report of the fire-arm, is a satisfactory proof of the prodigious disparity between the velocity of light and sound.

If the velocity of light, then, be so very great, it may be inquired why it does not strike against objects with a proportionate force? If the finest sand were thrown against our bodies with a hundredth part of this velocity, each grain would be as fatal as the stab of a dagger; yet our eyes, the most exquisitely sensible of all our organs of perception, receive its impressions without the smallest pain. But we have sufficient evidence to convince us that the minuteness of the particles of light is still more extraordinary than their velocity, and that their minuteness, therefore, is the cause of their being harmless. A lighted candle will fill a sphere of four miles in diameter, and may be extinguished without having lost any sensible portion of its weight; yet it must have diffused several hundreds of millions more particles of light than there could be grains in the whole earth, if it were entirely composed of the finest sand.

It is a principle in mechanics, that the momentum of moving bodies, or the force with which they strike, is proportionate to the quantity of matter they contain multiplied by their velocity; consequently, if the particles of light were not infinitely smaller than we can conceive, nothing could with-

stand their impulse. Light moves 2,000,000 of times faster than a cannon ball; consequently, if its particles were only equal in size to the 2,000,000th part of a grain of sand, they would produce an effect equal to that of sand from the mouth of a cannon. If, keeping this in mind, we further consider the facility with which light penetrates the hardest bodies, as glass, crystal, and even the diamond itself, through all which it finds an instant passage, and that it does not displace the smallest atom of dust which it encounters in its progress; we shall not hesitate to admit, that the particles of light cannot be equal in size to the 4,000,000th part of a grain of sand.

As the particles of light are continually passing from every luminous body, in all directions, it may be inquired why they do not interfere with each other in such a manner as to confound all distinct perception of objects, if not quite destroy the sense of seeing? Their velocity, however, enables us to answer these questions, by convincing us that they may be separated at least a thousand miles, and yet be perfectly efficient to the purposes of vision. It is an undoubted fact, that the effect of light upon the eye is not instantaneous, but that the impression remains after the light has been withdrawn. Of this any one may satisfy himself, by shutting his eye, after having looked for some time on a candle, a star, or any other luminous object, when a faint momentary picture of the object will remain. The same thing may be proved by whirling round a stick, the extremity of which is on fire; if the motion be quick enough, the perception of a complete circle of flame will be impressed on the eye. The actual duration, for a certain time, of the impression of light being thus proved, let it be supposed to continue distinct only for the 150th part of a second; then if one lucid point of the sun's surface emit 150 particles of light in a second, these will be amply sufficient to afford light to the eye without any intermission; and yet the particles emitted will be more than 1000 miles apart.

Notwithstanding the extreme tenuity of light, the task of actually measuring its momentum has not proved either too bold to be conceived, or too difficult to be executed. Boerhaave gave motion to the needle of a compass, by concentrating the rays of the sun upon it with a powerful burning-glass; and Mitchell, in later times, tried an experiment to the same purpose in a still more satisfactory manner. He constructed an instrument, in the form of a small vane or weathercock. It consisted of a very thin plate of copper, of about one inch square, which was attached to one of the finest harpsichord wires, about ten inches long. To the middle of the wire was fixed an

agate cap, such as is used for the smallest mariners' compasses, after the manner of which it was intended to turn; and the thin plate was balanced on the other side by a grain of small shot The instrument weighed ten grains; and to prevent its being affected by the vibrations of the air, it was inclosed in a glass box. The rays of the sun were thrown upon the plate of copper from a concave mirror of two feet in diameter; in consequence of which, the vane or copperplate moved, on repeated trials, with a gradual motion of about one inch in a second of time. The instrument weighing ten grains, and the velocity with which it moved being one inch in a second, the quantity of matter contained in the rays which fell upon the instrument in that time, was equal to the twelve hundred millionth part of a grain, the velocity of light exceeding the velocity with which the instrument moved in that proportion. The mirror containing about three square feet of surface, and mirrors in general reflecting only half the rays which fall upon them, the quantity of matter contained in the rays of the sun incident upon a square foot and a half of surface, is no more than one twelve hundred millionth part of a grain. But the density of the rays of light at the surface of the sun is greater than at the earth, in the proportion of 45,000 to 1. If in one second, therefore, one square foot of the sun's surface emit one forty-five thousandth part of a grain of matter, the supply will be adequate to the consumption of light; yet it will be little more than two grains a day, or about 4,380,000 grains, or 626 pounds, in 6,000 years; a loss which would have shortened the sun's diameter about ten feet, if it were formed of matter the density of water only.

By those who adopt the opinion that light is constituted by the vibrations of a subtile fluid, it has been urged, that if a flood of particles were incessantly streaming from the sun, the diminution of the bulk of that luminary would have become very perceptible from the diminution of his beneficial effects. But even if the preceding calculation of the emission of light be estimated far too low, when the immensity of the sun's diameter, which amounts to 883,246 English miles, is considered, we shall see little reason to justify the apprehensions of its being exhausted, however extravagant our ideas of the duration of the present system of nature, and although we reject the great probability that, like our atmosphere, it is provided with the means of its own perpetual replenishment.

It has been objected to Mitchell's experiment, that the air, rarefied by his mirror, was sufficient to give motion to the vane, although the light which fell on it had no momentum whatever; but it has been found that precisely the same

motion is produced in vacuo as when the glass case is filled with air. The fact that light has momentum may therefore be considered as proved, though the deductions drawn from the experiment relative to the quantity of it, are liable to much uncertainty.

Another argument in favour of the extreme tenuity of light, and of its particles following each other at an immense distance,[1] is the well known fact, that the rays collected by the strongest burning-glass, will not inflame the most combustible matter while they merely pass through it. A phial containing spirit of wine will not be set on fire; but if the spirit is poured into a spoon or any opake vessel, which stops the progress of the concentrated rays, inflammation instantly results. This familiar experiment enables us to account for the cold experienced at the summits of high mountains. The atmosphere is not warmed by the mere passage of the rays through it; these rays first heat the earth, where they are first stopped, and the earth then communicates its own temperature to the air, which being a very bad conductor of heat, the lower, denser stratum of it, becomes the chief residence of its warmth. Such parts, therefore, as are elevated above the general surface of the earth, derive, in proportion to their height, a diminished advantage from this circumstance, and though they may receive as many rays as an equal extent of burning desert, yet the surface they contain is so trifling, when compared with the stratum of air on a level with them, that the heat produced is abstracted as quickly as it is formed.

The next property of light which demands our attention, is, that it is propelled from every luminous body in *right lines*. This is evident from an experiment which any person may make with a bent tube, through which nothing can be discerned, provided it be so much bent that nothing can pass through it in a right line. Another proof of the same fact, is, that shadows are bounded by right lines drawn from the luminous body past the contour of the body casting the shadow.

It is generally supposed, according to this principle, that those bodies only are *transparent* whose pores are such as to permit the rays of light to pervade them in a right line; and that those bodies are *opake*, which intercept the rays like the bent tube.

Every ray of light carries with it the image of the point from which it was emitted. If, therefore, the pencils of rays from every point of an object, are united in the same order in which they proceeded when first emitted, they will form a perfect image or representation of that object, at the place

where they are thus united. The rays of light proceeding in straight lines, it is obvious, that to make an object visible, at any place to which a straight line can be drawn from it to the eye, they must be detached from every physical point of it in all directions; but only those rays which enter our eyes can render them visible to us. Thus the object ACB, fig. 2, pl. I, is rendered visible to an eye in any part where the rays A*a*, A*b*, Ac, A*d*, B*a*, B*b*, Bc, B*d*, C*a*, C*b*, Cc, C*d*, can come; and these rays affect our sight with the sense of different colours and shades, according to the properties of the body from which the light is reflected. However confused the figure may appear, those, to whom the subject is new, will observe that the rays are only made to proceed from three points; and hence they may be enabled to form some slight conception of the numberless crossings of the rays, in order that every part of a body may be visible, in whatever direction it is looked upon.

Here perhaps we may allow the young reader, before we pass on with didactic philosophy, to contemplate, for a moment, that luminary from which all light proceeds. The barbarous and the civilized, the ignorant and the wise, have in all ages regarded the sun as the grandest object of the whole visible creation. With what delight does the lover of nature view, in what glowing colours has the enraptured poet painted, his rising, his meridian, and his setting glories. Allusions to the sun, and to light, constitute the most beautiful expressions and figures of speech in all languages; and such are the ideas of association connected with them, that frequency of repetition, or even abuse, can scarcely render any of them contemptible. A few might be adduced, which accompany only triteness of sentiment, and feebleness of diction; but genius has still the power of eliciting new descriptions and combinations of allusion, as poetically beautiful, as philosophically correct. Thomson's apostrophe to the sun is distinguished for grandeur of idea, and simplicity of expression.

"Great source of day, best image here below
Of thy Creator, ever pouring wide,
From world to world, the vital ocean round."

Refrangibility of light.

The natural progress of the rays of light, we have already shewn, is in straight lines; yet, like all other matter, light is influenced by attraction, which sometimes turns it out of its direct course. This happens when it passes out of one medium into another of different density, as from air into water or glass, or from water or glass into air. This disposition or capability of light to be bent, is called its *refrangibility*, and the change of direction actually assumed when the rays enter another medium, is called *refraction*.

A very easy experiment will convince any one that light is influenced by some power or other when coming out of a different medium: put one end of a stick into water, and it will appear at the surface as if it were broken. This effect is owing to the rays of light being attracted or drawn out of their direct course, as may be proved in a variety of ways. Place a shilling, or any other conspicuous but small object, at the bottom of a basin, and then retire to such a distance, that the edge of the vessel just prevents its being seen. Let the vessel be then filled with water, and the shilling will be perfectly visible, though neither it nor the spectator have changed places in the slightest degree. Another experiment of the same nature, and more easily managed by one person, is the following: take a basin, or any convenient vessel, and place it in such a situation that the shadow of a lighted candle will fill one half of it; hold the end of a ruler or stick exactly on the place where the shadow terminates; then pour water into the basin, and the shadow will be seen immediately to withdraw from the ruler. Increase the quantity of water, and the distance to which the shadow will retreat, will also be increased.

It is necessary to observe, that only those rays which enter another medium *obliquely*, suffer refraction, for a ray which falls perpendicularly is equally attracted on all sides, and therefore has no tendency to deviate in any direction. In the experiment with the shilling, the spectator looks at it in an oblique direction; and the rays proceeding from it, by which it is rendered visible after the water has been poured in, are bent towards him, on entering the air. A ray of light, AC, fig. 7, pl. I, which passes obliquely from the air into water at C, instead of continuing its course to B, takes the direction CH; and the reverse is equally true, a ray of light from H, reflected in the direction HC, instead of continuing its rectilinear course, proceeds in the direction CA; therefore an object at H is seen by an eye at A, as if it were actually at B, every

object appearing to be in the direction of those rays which last approached the eye.

That the rays of light actually proceed in the direction ascribed to them, is not merely a matter of speculation; we may have ocular demonstration of the fact in a variety of ways, of which the following is one: Take an empty basin, and on the bottom of it fix marks at a small distance from each other, then take it into a dark room, and let in a ray of light, and where the rays fall upon the floor, place the basin, so that its marked diameter may point towards the window, and that the light may fall upon the mark most distant from the window. Pour water into the basin, and it will be found that the ray which before fell upon the most distant mark, will, by the refractive power of the water, be turned out of its straight course, and fall two or three marks nearer the centre of the basin. The water may now be rendered rather turbid without destroying its transparency, which may easily be done by the addition of a few drops of milk, then on filling the room with dust, the light will be completely visible, both in its passage through the air and the water. Three directions of the ray will be distinctly perceived; the direction of incidence, or that in which, from the aperture, it falls obliquely on the water; that of reflection, equal to that of incidence; and that of refraction, which commences at the surface of the water, and is continued in a direct line to the bottom of the basin. All things remaining the same, place a small piece of looking-glass at the bottom of the basin, where the refracted beam falls, and it will be reflected back again through the water, and in passing out of the water into the air, will be again refracted or turned out of its course.

The greater the density of any medium, the greater is its refractive power; and of two refracting media, that which is of an oily or inflammable nature, will have a greater refracting power than the other.

The *incident angle* is the angle made by a ray of light and a line drawn perpendicular to the refracting surface at the point where the ray enters the surface; and the *refracted angle*, is the angle made by the ray in the refracting medium with the same perpendicular continued. The *sine* of the angle is a line which serves to measure the angle, being drawn from a point in one leg perpendicular to the other. In fig. 7, pl. I, ACD is the incident angle; HCE is the refracted angle; BCH is the angle of deviation; AF is the sine of the angle of incidence; HG is the sine of the angle of refraction.

If the incident ray, AC, fell in a more oblique direction than is represented by fig. 7, the refraction would be still greater; but in all cases of similar media, the angle of refraction will always be found to bear a regular and constant proportion to the angle of incidence; or in the language of opticians, the sine of incidence is to the sine of refraction in a given ratio or proportion, and this ratio is discovered by experience. In the present instance, if with a pair of compasses we divide the sine of incidence into four parts, the sine of refraction will be exactly three of those parts. Hence, when a ray passes out of air into water, the ratio is said to be as 4 to 3; when out of water into air, the ratio is reversed, and therefore becomes as 3 to 4. The ratio out of glass into air is as 2 to 3; consequently out of air into glass it is as 3 to 2.

It will be observed, from what has been just said, that in passing into a denser medium, light is refracted *towards* the perpendicular, that is, the angle of refraction is less than the angle of incidence; on the contrary, when passing into a rarer medium, it is refracted *from* the perpendicular. The inspection of fig. 7, will render this evident; the angle of incidence, ACD, being so much larger than the angle of refraction, ECH, the refracted ray CH, is nearer the perpendicular than if, proceeding in a right line, it had gone to B.

It may seem, at first view, a little extraordinary, that light should pass more directly through a dense than through a rare medium; but we have already seen that light is subject to attraction, and Sir Isaac Newton discovered and demonstrated, that this power is the cause of refraction. A circumstance that confirms the truth of this theory, is the known fact, that the change in the direction of the ray commences, not, as might be supposed, when it comes in contact with the refracting medium, but a little before it reaches the surface, and the incurvation augments in proportion as it approaches the medium Then as the attractive power of different substances are proportionate to their densities, we discover at once the reason of the ray being bent *towards* the perpendicular on entering another medium of greater density, and *from* the perpendicular, on entering a medium of less density.

In passing from a dense into a rare medium, however, there is a certain degree of obliquity at which the refraction is changed into reflection. In other words, a ray of light will not pass out of a dense into a rare medium, if the angle of incidence exceeds a certain limit, but will be reflected back. Thus a ray of light will not pass out of glass into air, if the

angle of incidence exceeds 40° 11′, or out of glass into water, if the angle of incidence exceeds 59° 23′.

A knowledge of refraction will enable us to explain a variety of curious phenomena, and on some occasions will usefully direct our judgment. When a spectator stands on the bank of a river, just above the level of the water, the bottom will be one-third deeper than it appears. This is a necessary consequence of the rays from the bottom being bent from the perpendicular, and consequently inclined towards the spectator, on passing out of the water to his eye. Those who shoot fish in the water, soon obtain a practical knowledge of this deception, for they find that they cannot hit their mark, unless they aim considerably below the place which it seems to occupy. A proof of the fact may very easily be obtained: immerse a stick or straight rod of any kind, perpendicularly in water, until the part which is immersed appears of equal length with the part above; upon taking it out and measuring the parts, it will be found that they are to one another as 4 to 3. We can now have no difficulty in accounting for the broken appearance of an oar, when partially immersed in water. Let FGH, fig. 8, pl. II, represent an oar, the part GH being in the water, and the part GF out of it. The rays sent to the eye from H, will appear to come from I, nearer to the surface of the water, and as every part of GH will appear proportionately nearer the surface, the part GH will appear to make an angle with the part GF.

It is not merely objects that are partly out of water, which lose their natural appearance from refraction; those which are entirely immersed, especially when they are large, and lie at a considerable depth, appear distorted in a variety of ways. A flat-bottomed basin seems deeper in the middle than at the sides, and a long straight leaden pipe appears to be curved. The reason is, that the rays from the more distant extremities come in a more oblique direction on their emergence into the air, and consequently suffer a greater refraction than the rest.

The distortion of objects seen through a wrinkled or crooked pane of a window, can have escaped the observation of few; it arises from the unequal refraction of the rays which pass through the glass. In looking through an even pane of glass, about the tenth of an inch thick, objects appear nearly one-thirtieth part of an inch out of their true place; but as they all maintain the same relative situation, the error is not perceived.

A stranger to this subject would scarcely suspect, that we never see the stars in the place where they really are, and that we actually see the sun, and other heavenly bodies, before they

are risen above the horizon. Our atmosphere decreases in density as it increases in height, and though, at the tops of the highest mountains, its pressure is so diminished, that breathing is difficult, and the blood often gushes through the skin, yet, at the elevation of forty-five miles, it is still capable of refracting a ray of light. When, therefore, the sun is sunk so far below the horizon, that his rays can only strike the upper part of the atmosphere, he still remains visible, because, instead of passing directly onward, the rays are attracted towards the perpendicular, and consequently bent towards the spectator on the earth. To exhibit this effect to the eye, let fig. 9, represesent the earth surrounded by its atmosphere. HO is the visible horizon of a spectator standing at P. S represents the sun as yet really below the horizon, from which a ray of light ascends, and falling on the upper part of the atmosphere, is, by the attraction it there experiences, bent out of its direct course towards D, into the oblique one IP, by which means it falls upon the eye of the spectator, who, perceiving the sun in the direction of the refracted ray, will suppose it to be at R, which is higher than its true place by more than a diameter. The length of time that the sun appears above the horizon, while he is actually below it, varies a little with a number of circumstances, but chiefly with a difference of latitude. At the approach of summer, near the poles, the sun becomes constantly visible for two or three weeks before he actually rises above the horizon; and at the approach of winter, when he has sunk below the horizon, his presence, from refraction, continues to cheer these dreary regions for a similar space of time. The heavenly bodies, when in the zenith, are not subject to any refraction; but when in the horizon, they have the greatest of all: from the horizon to the zenith, the refraction continually decreases.

Mankind have availed themselves of the principle of refraction, to a most excellent purpose, in the construction of lenses; for by grinding the glass thinner at the edges than in the middle, those rays of light which would strike upon it in a straight line, or perpendicularly, if it were plain, strike upon it obliquely, and the refraction they suffer causes them to converge; on the contrary, by making the glass thinner in the middle than at the sides, the rays are refracted the contrary way, and therefore become divergent.

The consideration of refraction through lenses may perhaps be rendered more clear, if we reflect, that all curved surfaces are composed of a number of straight lines, or points, infinitely short, and inclining to each other like the stones in the arch of a bridge. In fig. 10, pl. II, parallel rays are represented as

falling upon a surface of this sort; and it is evident that those only which enter the middle part will go on in a straight direction; those which strike the sides will strike them obliquely, and will consequently be made to converge. If the surface, then, was a perfect curve, as in fig. 11, it is plain that only the ray which strikes the centre part of the curve will enter it in a straight direction; all the rest will be more or less refracted, according to the degree of obliquity with which they strike the surface, and the whole of the refracted rays will converge to a point called the focus.

Glasses are usually ground for optical purposes into eight different forms. 1. The glass may be flat on both sides, like the pane of a window. 2. It may be flat on one side, and convex on the other. 3. It may be convex on both sides. 4. It may be flat on one side, and concave on the other. 5. It may be concave on both sides. 6. It may be convex on one side, and concave on the other, like the crystal of a watch. 7. It may have one side, which must be convex, ground into little facets, while the other side is plane. 8. It may have some considerable length, in a triangular form.—The sections of these various forms of glasses are shewn at fig 12, pl. II. and they are distinguished by the following names: the glass No 1, is called a *plane glass*, as its sides are parallel; No. 2, is called a *plano-convex* glass; No. 3, a *double-convex* glass; No. 4, a *plano-concave* glass; No. 5, a *double-concave* glass; No. 6, a *meniscus* glass; No. 7, a *multiplying* glass; and No. 8, a *prism*. The term *lens* is given to such glasses as either magnify or diminish the apparent size of objects viewed through them; Nos. 2, 3, 4, and 5, are therefore lenses; No. 6 is also a lens, when its surfaces are portions of different spheres; but when they are of equal radii, it has only the effect of a plane glass.

From the view we have already given of refraction, the effects of the first seven of these glasses will be easily understood.—The prism will receive a distinctive consideration. A ray entering the plane glass, No. 1, will indeed be refracted, but it will suffer another refraction on its emergence, which will rectify the former; the place of the object will therefore be a little altered, but its figure will remain the same. Suppose AB, fig. 13. to represent a solid piece of glass with two parallel surfaces, an incident ray EF, will be refracted into FG, and FG will be refracted on passing from the second surface into GH, parallel to the original direction EF.

If parallel rays enter the plano-convex glass, as shewn by fig. 11, the ray E will be refracted upwards to F, the ray K will be refracted downwards to the same point; there they

will cross, and then go onward in a straight line, and continue to diverge, till intercepted by some obstacle.

When parallel rays fall upon a double-convex glass, KG, they will be refracted still more abruptly, and meet sooner in a point or principal focus at F. The distance of this focus is equal to the semi-diameter of the circle which the convexity of the glass continued would produce. Either this glass or the former, as they collect the rays of the sun into a point, will burn at that point, the whole force of the rays that pass through them being concentrated there.

From all luminous objects, the rays of light proceed in a state of divergence; but when the distance from which they come is very great, the quantity of divergence is too small to require notice. The sun, for example, is so immensely distant, that his rays are always considered as parallel; and it is only parallel rays which are converged to a focus, in the manner shewn above. Divergent rays, proceeding from a point, as the flame of a candle, will be differently affected. If, therefore, we place a candle exactly at the focal distance of a single or double-convex lens, as at F, figs. 11 and 14, the rays will emerge parallel to each other. If the candle is placed nearer to the glass than its focal distance, the rays, after passing through the glass, will no longer be parallel, but separate or diverge; if the candle be placed still further off, the rays will then strike the glass more nearly parallel, and will, therefore, upon passing through, converge or unite at a distance behind the glass, more nearly approaching the distance at which parallel rays would be converged.

After the rays have united or converged to a focus, they will cross each other, and form an inverted picture of the flame of a candle, which may be received on a piece of paper placed at the meeting of the rays behind. The cause of the inversion of the image is therefore very evident; for the upper rays, after refraction, were such as came from the under part of the luminous body; and the under rays, on the contrary, came from the upper part.

The foregoing theory may be demonstrated with a common reading glass. If a candle be held so near a glass of this sort, that the rays passing through, fall upon a screen or wall with a bright spot just as large as the glass itself, the candle is then at the focal distance, and it is clear that the rays which struck the glass divergently, are refracted parallel, or the spot of light could not be just the size of the glass. If the candle is held nearer than the focal distance, the rays will then fall more divergently upon the glass, and will consequently, after refraction, still have so much divergence as to form a very

broad spot of light upon the screen. If the candle be held at a much greater distance than the focus, the rays will fall upon the glass more nearly parallel; and therefore, when they are refracted, they tend to unite and converge behind the glass, and will form upon the screen a small speck of vivid light, which, if closely examined, will appear a perfect image or picture of the candle.

In looking through a plano-convex or double-convex lens, the objects we examine will appear magnified; consonantly with the general rule, that we see every thing in the direction of that line in which the rays last approached the eye; and it will be understood when we come to treat of the eye, that the larger the angle under which any object is seen, the larger that object will appear. That the convergence of the rays of the convex-lens, enlarges greatly the angle of vision, and consequently enlarges the apparent size of objects seen through it, will be evident, if we continue the lines in the direction of their convergence, thus, FK to L, and FG to R, fig. 14.

From lenses the reverse in form to those we have hitherto been considering, we shall naturally expect opposite effects. Accordingly, the attractive and refractive powers of the lenses, Nos. 4 and 5, fig. 12, are not towards the centre, but towards the circumference. Parallel rays falling upon them are made to diverge, or are dispersed. Rays already divergent are rendered more so, and convergent rays are made less convergent. Hence objects seen through one of these glasses appear smaller than to the naked eye. Thus, let *a b*, fig. 15, pl. II, represent an arrow, which would be seen by the eye, if no lens were before it, by the convergent rays *c a*, *i b;* but if the double-concave glass DH is interposed between the object and the eye, the ray *a c* will be bent towards *g*, and the ray *b i* will be bent towards *k*, and consequently both will be useless, as they do not enter the eye. The object then will be seen by the rays *a o*, *b r*, which, on entering the glass, will be refracted into the lines *o c* and *r i;* and according to the rule just laid down, the object will be seen in the last direction of these rays; therefore, as the angle *o c r*, is so much smaller than the angle *a c b*, the arrow necessarily appears diminished, and as with the diminution of its apparent size, we connect the idea of its being further off, it seems to be at the distance *n m*.

The meniscus acts like a convex glass, when it is thickest in the middle, that is, when its convex surface is a portion of a less sphere than its concave one; on the contrary, when it is thinnest in the middle, or has its concave surface a portion

of a less sphere than the other, it has the effect of a concave lens. Sometimes, to distinguish these different forms from each other, when the glass magnifies, it is called a convexo concave lens; when it diminishes the apparent size of objects, it is called a concavo-convex lens; and the term meniscus is restricted to such as have both their surfaces equally arched, and, therefore, like the crystal of a watch, neither magnify nor diminish.

The *axis* of a lens, is a line supposed to be drawn through the centre of its spherical surface or surfaces. When one side of the lens is plane, the axis of course falls perpendicularly upon that side. The axis of a lens continued, would pass exactly through the centre of that sphere, of which the lens is the segment. This will be apparent from an inspection of figs. 11 and 14, and in fig. 12, a line is drawn representing the axis of the lenses. When opticians mention the focal distance of a convex lens, they mean the focus of parallel rays; but when they wish to be more precise, the focus of parallel rays is distinguished by the term *principal* focus. Mathematicians demonstrate, that the principal focus of a plano-convex lens is at a distance from the convex surface equal to the diameter of the sphere of which it is a part; and that the principal focus of a double and equally convex lens is at half the same distance. The principal focus of these lenses may therefore be found, with sufficient accuracy for common purposes, by holding a sheet of paper behind the glass, when exposed to the rays of the sun, and observing when the spot is smallest, and when the paper most readily burns. Or when the focal distance does not exceed two or three feet, it may be found by holding the glass at such a distance from the wall opposite a window, that the image of the sash may appear distinct upon the wall. When accuracy is desirable, and the focal distance exceeds two or three feet, the following method may be pursued: cover the lens with a piece of paper or pasteboard, in which two round holes have been made; each hole being at an equal distance from the edge of the lens, and in one of its diameters. Direct the axis of the lens thus covered to the sun, and receive upon a piece of paper the circles or white spots produced by the two holes, which will be observed gradually to approach each other as the paper is moved farther off; at last they will coincide; and if the distance of the lens from the paper be increased, they will again separate. The distance of the paper from the glass, when the circles coincide, is the focal distance required.

When a lens is more convex on one side than the other, and both radii are known, the following rule will determine

the focus: as the sum of the radii of both convexities, is to the radius of either, so is double the semi-diameter of the other to the distance of the focus; or divide the double product of the radii by their sums, and the quotient will be the distance sought.

As convex lenses cause many rays to enter the eye which would otherwise have been scattered and dispersed, the objects seen through them appear clearer and more splendid than when viewed by the naked eye. They should always be made as thin as their curvature will admit, otherwise the brilliancy of the image will be lessened without necessity, by the rays which, though they enter the glass, are reflected or sent back.

A large object, seen through a lens which is very convex, appears more or less distorted; this proceeds from the refraction not being equal at all points, and the degree of it is proportionate to the size of the object compared with the focus of the glass. When the object is not much too large, its extremities only appear confused.

To ascertain the focal distance of a globular glass vessel containing water, such as a decanter, make a round hole, about an inch diameter, in a piece of brown paper, which must then be pasted on one side of the body of the decanter; hold the covered side of the decanter to the sun, that the perpendicular rays may pass through the middle of the water, and the emergent rays will be collected to a focus, whose nearest distance from the decanter will be nearly equal to the radius of the body of it, as will appear by receiving the rays upon a paper held at that distance. That this effect is owing to the water, and not to the glass, may be proved by emptying the decanter; for the light that then passes through the hole, will be as broad as the hole itself, at all the distances of the paper from the decanter, a circumstance of which we might also be assured, from considering, that the sides of the empty decanter can only act like two meniscus glasses placed at a little distance from each other. If a solid globe or ball of glass, be covered and tried like the decanter, the distance of the focus from the nearest part of the ball, will be one quarter of its diameter.

Parallel rays, on passing through a single or double-concave lens, immediately diverge; hence the term focus cannot be applied to a concave lens, in the same sense as to a convex lens. A concave lens has only what is termed a *virtual focus*, the distance of which from its surface, is the same as that of a convex lens of equal radius, but it is before the glass, because it denotes that point from which the rays, after their last refraction, appear to diverge. To find the focal distance

of a concave lens, let the lens be covered with a piece of paper, containing two small circular holes; and on the paper for receiving the light, describe also two small circles, but with their centres twice as far apart as the centres of the circular holes. Move the paper backwards and forwards, till the middle of the sun's light, coming through the holes, falls exactly on the middle of the circles, and the distance of the paper from the lens will then be the focal length required.

To find the vertex or centre of a lens, hold it at some distance from the eye, and observe the two reflected images of a candle made by the two surfaces. Move the lens till these images coincide, and the point of coincidence is the vertex, which, if in the middle of the surface, the glass is truly centred.

To understand the effect of the multiplying glass, No. 7, fig. 12, pl. II, it is only necessary again to revert to the general principle, that objects appear in the direction of the line last described by the rays that render them visible. Hence, if the object B, fig. 1, pl. III, is seen through the glass EH, by the ray BA, that passes through the surface FG, the object, by the eye at A, will be seen at B; the ray BG passes through the surface GH, and after refraction, comes to the eye in the direction AD, as if it proceeded from D, and therefore the object appears at D; and for the same reason, through the surface FE, it appears at C; consequently, there will be the appearance of as many objects as there are flat surfaces on the glass, for each of them shews the same object in a different place.

To become familiar with the laws of refraction, and the properties of lenses, the student should make experiments with lenses of different foci, diameters, and colours. The room should be darkened, and the sun's rays admitted through an aperture cut in the shutter, or through a tube placed in the shutter, and moveable in any direction. The lenses should be fitted into cells connected with a sliding board, or adapted to convenient frames. By these means, the lenses may be combined in any way required. It would be proper, also, to have lenses ground to the figure of a meniscus, or watch-glass, and fitted up so that two or more of them might be connected in one frame, with a view to include fluids between them, and thus exemplify the refractive powers of fluid lenses. The dust usually in motion, will, in the darkened room, give the various and natural figures of the converging and diverging pencils of rays.

Of the Reflexibility of Light.

The disposition or capability of the rays of light to be turned back into the medium from whence they came, is called their *reflexibility:* the change of direction produced by their being actually turned back, is called *reflection.*

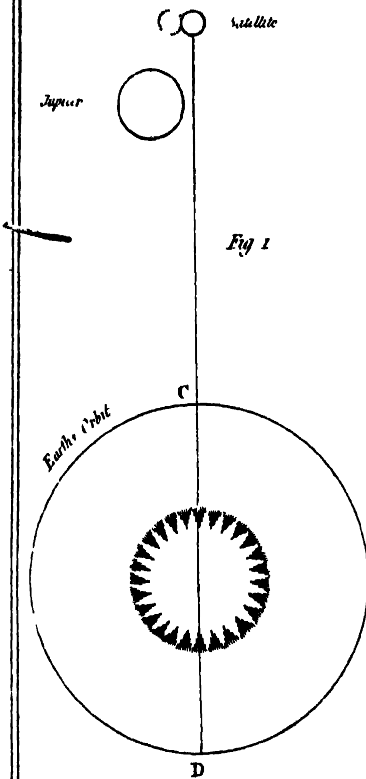
The property which bodies possess of reflecting light, is attributed by Sir Isaac Newton to the principle of repulsion. In confirmation of this theory, it is justly remarked by him, that those surfaces, which to our senses appear smooth and polished, are found, when viewed through a microscope, to abound with inequalities; if, therefore, the power which produces reflection, did not act at some distance from the reflecting surface, these inequalities would prevent the rays from being reflected with so much regularity as we find they are. Other theories have been proposed, to account for reflection, but none of them appears more probable in itself, or so reconcileable with the facts connected with this property of light. But however well founded the opinion, that light is reflected by the power of repulsion, and consequently before it comes into absolute contact with the reflecting surface; it will not be necessary to introduce the circumlocution required to express this idea, in treating of the general phenomena; the incident rays will always be spoken of as actually impinging on the reflecting body, from which they rebound, as a perfectly elastic ball would rebound from a marble slab.

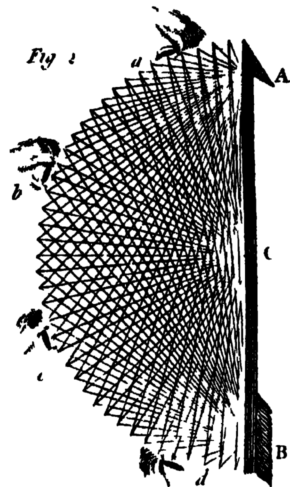
All objects which are not themselves luminous, are rendered visible by reflection. Even glass, crystal, water, and the most pellucid media, reflect a part of the rays of light which fall on them, or their forms and substance could not be distinguished; on the contrary, the whole of the incident light is not reflected from any surface, however bright, smooth, and opaque. It is calculated that the best mirrors reflect little more than half the light they receive.

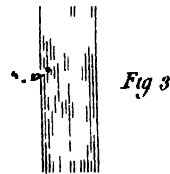
From the account we have given of refraction and other properties of light, the student is already fully apprized, that it is the rays emanating from any given point, which assure our sight of the existence of a body at that point; and that, as in the instance of a fish in the water, if the direction of the rays be changed in any manner, the sense of sight, always referring the place of an object to the point in the direction of the last course of the rays, is easily deceived, and will suppose an object to be where it is not. This it will be necessary to bear constantly in mind while we pursue our present subject; for in connection with another law of nature, it forms the

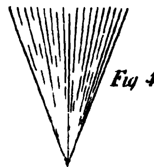
key by which all the phenomena of reflection are explained. The other law to which we allude, is, that *the angle of reflection is always equal to the angle of incidence.* In fig. 6, pl. I, *a d* is an incident ray, falling upon the surface *e f*, from which it is reflected in the direction *d b;* hence the angle of incidence, *a d c*, is exactly equal to the angle of reflection *b d c*, from on either side of the perpendicular *c d*, the obliquity of the ray is the same, and consequently when the reflecting surface is a plane, the obliquity of the line of incidence and reflection are also equal, when measured from it. It is only the rays which fall obliquely upon a reflecting surface, that are reflected in an angle to their direction of incidence; those rays which fall perpendicularly, return in precisely the same direction.

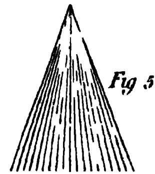
To pursue the consequences deducible from these principles, or their application to particular effects, will soon shew how much depends upon them. Let NO, fig. 2, pl. III, be considered as a ray of light striking perpendicularly on the surface of the mirror AB, and it is reflected back in the same line. The ray DO, coming from the luminous body D, strikes the mirror obliquely, and is reflected to the eye in the line OE, thus making the angle of reflection, NOE, equal to the angle of incidence DON, and the object is seen at S, in the direction of the reflected ray. To be a little more explicit, with regard to the last particular, it must be recollected, that an object is rendered visible, not by single rays proceeding from every point of its surface, but by pencils of rays, or collections of divergent rays issuing from every point. These pencils of rays are afterwards, by the refractive powers of the eye, converged again to points upon the bottom of the eye or retina, and these points of convergent rays in the eye, are correspondent to the points of the objects, from which the rays diverged. Hence, as the pencils of rays strike the mirror while they are in their divergent state, from the equality of the angles of incidence and reflection, they are reflected in the same state, and converge exactly as they would have done if they had not been intercepted by the mirror, but had gone on to G, a distance equal to the incident and reflected course taken together. In consequence of this identity in the convergence of the rays, and the general rule that the place we assign to objects is in the last direction of the rays, the two lines, namely, that from the object to the mirror, and that from the mirror to the eye, are united in the mind of the spectator, and the object is consequently seen at S, just as far behind the mirror as the object is before it. Another figure will, perhaps, render this more

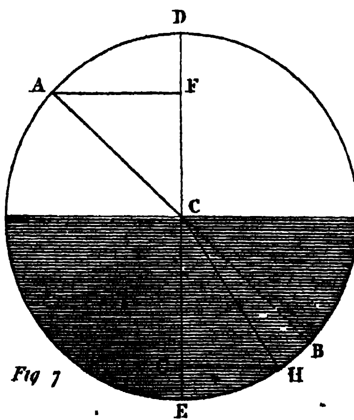


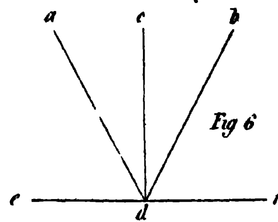




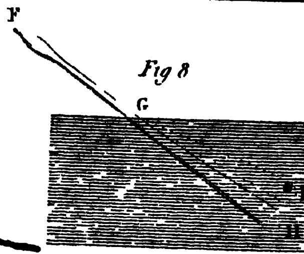


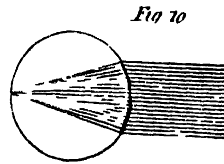


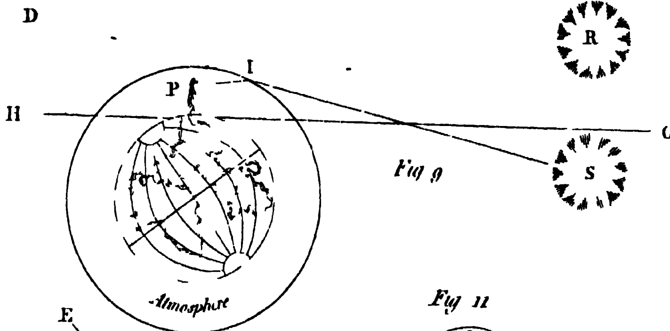


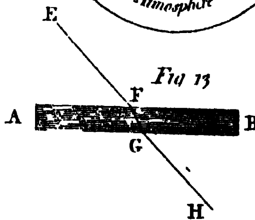


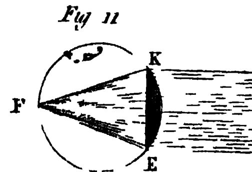
Barlow sculp

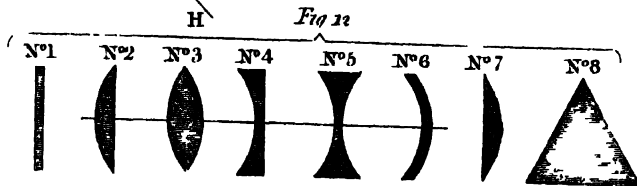

F
Fig 8
G
H
D

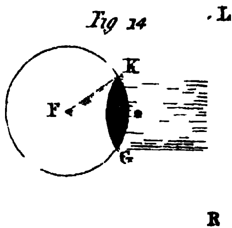

Fig 10

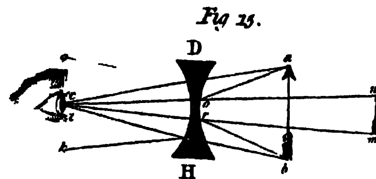

R
I
P
H
O
S
Fig 9
Atmosphere


E
Fig 13
F
A
B
G
H


Fig 11
K
F
E


Fig 12
N°1
N°2
N°3
N°4
N°5
N°6
N°7
N°8


Fig 14
L
K
F
G
R


Fig 15.
D
a
n
m
b
H

evident: the lines DC, fig. 3, pl. III, are the lines of incidence, CB are the lines of reflection, and these form equal angles on the surface of the mirror, so that all the rays coming from the object, and falling upon the mirror at C, will strike the eye at B, and the reflected image will thus become visible. Now every object appears to be in a straight line from the eye, and as no alteration is made in the relative position of the rays, but only in their direction, the body DD, when it comes reflected to the eye, will appear to be at AA, because rays from thence would, at the mirror, exactly coincide with the rays DC, DC, and would, by the time they arrived at BB, be converged to an equal focus.

Hence we shall not find it difficult to understand why a man may see his whole figure in a plane looking-glass only half as long and half as broad as himself; for the image is seen under an angle as large as the life: the mirror is exactly half way between the image and the eye, and therefore the divergent rays, by which the image is seen, only cover at the glass, a space equal to half the size of the man himself.

When light is reflected from convex or concave mirrors, it obeys precisely the same law as from plane mirrors, however extraordinary the effects they produce may at first sight appear. To understand the manner in which they act, it will be proper to recur to an observation formerly made respecting spherical surfaces: all curves or arches are to be considered as composed of a multitude of infinitely short lines or points, lying obliquely to one another. Parallel rays, therefore, fall upon them more or less obliquely at every point of incidence except the centre. This part of the subject may perhaps be best elucidated, if we consider, in the first place, the direction given to rays which fall upon two plane mirrors inclined to each other in opposite directions. Thus, in fig. 4, pl. III, the rays AB, CD, which would fall perpendicularly on a flat surface in the direction IK, strike obliquely upon that which is opposed to them, and instead of being reflected parallel, are reflected divergently. For the same reason, convergent rays would be reflected with less convergence by such a surface as this, and divergent rays would be rendered still more divergent towards E and H.

Fig. 5, which is the reverse of the preceding, will serve to shew us the nature of reflection from concave surfaces. Here the parallel rays AB, CD, which would have been reflected parallel by a plain mirror, are made to converge, and meet at L, because, instead of striking this mirror in a direct line, they strike it obliquely, and the planes of inclination are inclined to each other, and therefore convergent rays will be reflected with

greater convergence, and divergent rays will have their divergency lessened.

As a convex mirror diminishes the convergency of the rays which fall upon it, the effect it produces is to diminish the apparent size of objects; because the visual angle is diminished, that is, there is not so large a picture formed in the eye, as when the object itself is seen without the mirror. But a concave mirror, on the contrary, enlarges the visual angle, or picture of an object on the eye, and consequently its effects are the reverse of the former. Reflection, then, from a *convex* mirror, corresponds to refraction through a *concave* lens; and upon the same principle, reflection from a concave surface corresponds to refraction through a convex lens.

More particularly to exemplify this theory, let AB, fig. 6, pl. III, represent a dart, which is seen in the convex mirror CD. Though rays issue from the object AB in all directions, yet it is seen only by means of those which are included within the space ON, because no other can be reflected to the eye at R. If the rays had gone forward in their original direction, they would have united at P, and the object would have been seen of its full size; but as, from the nature of a convex curve, the angle of reflection cannot be equal to the angle of incidence without diminishing their convergence, the angle SRT is less than the angle APB, and the image at L appears smaller than the object, and nearer to the surface of the mirror. The reason of this last effect has been already explained, when it was observed, that objects are rendered visible, not by a single ray, but by pencils of divergent rays proceeding from every point of them; and that the eye transfers the place of the object to the place where these pencils of rays unite in points. Suppose, then, a radiant point G, fig. 7, sends forth a pencil of divergent rays which falls on the convex mirror AB; the rays of this pencil will diverge still more after reflection, and therefore they will appear to come from a point nearer the eye than if their divergency had not suffered any change.

For these reasons, a person looking at his face in a convex mirror will see it diminished. This is shewn by fig. 8, pl. III; though rays proceed from every part of the face, it is only the rays that fall on the mirror between C and R, that can be reflected to the eye; the rays CR being therefore rendered less convergent, he will see his chin along the line OS, and the forehead along the line ON; the angle of vision being thus reduced, all the rest of the features will be proportionately reduced.

When large objects are seen in a convex mirror, they not only appear, according to its curvature, smaller than they really

are, but somewhat distorted. The reason of this is, that the different points of the object are not at an equal distance from the mirror, and consequently they are reflected to the eye under different angles. Glass globes, lined, like looking-glasses, with an amalgam that converts them into mirrors, are sometimes suspended in apartments as an ornamental piece of furniture. In these, the company seated in a room, or round a table, are represented by very minute images, which appear very near their surface, and are always, though beautiful, in some degree distorted. Latterly, convex mirrors, fitted in a frame, have almost superseded the globes, over which they have several advantages: they can be placed against a wall as conveniently as a picture; they can be made the segment of a larger sphere than it would be convenient to have entire; and in particular, they can be ground to a regular figure, whereas the globes are only blown glass, and therefore can never be true.

The effects of concave mirrors may be gathered from the considerations already premised; but though it may introduce some repetition, it will be proper to consider them separately. Their general effect is to render convergent rays more convergent, and consequently they have the power of magnifying. By fig. 9, pl. III, is represented a face looking at itself in the concave mirror IK, and the extreme of those rays which can be reflected to the eye are exhibited, one from the forehead, and one from the chin. These lines, *a c* and *m n*, are reflected to the eye at O, which sees the image in the line of reflection, and in the angle DOQ, and therefore evidently magnified, and at a small distance behind the mirror.

The magnifying effect of a concave mirror, is, however, only perceived when the object is nearer to it than its centre of concavity, or centre of the sphere to which the curve of the mirror belongs. When we come to the description of the telescope, the reader will better understand how the image is formed by the large concave mirror of that instrument, if we here refer to another diagram. Let A *c* B, fig. 10, pl. III, be the reflecting surface of a mirror, whose centre of concavity is at C; and let the upright object DE, be placed beyond the centre C, and send out a conical pencil of divergent rays from its upper extremity D, to every point of the concave surface of the mirror, A *c* B. But to avoid confusion, we only draw three rays of that pencil, as DA, D*c*, DB. From the centre of concavity, C, draw the three right lines, CA, C*c*, CB, touching the mirror in the same points as the three rays of the pencil from D, and all these lines will be perpendicular to the surface of the mirror. Make the angle CA*d*, equal to the angle DAC, and draw the right line A*d*, for the course of the reflected ray

DA: make the angle C*cd*, equal to the angle D*c*C, and draw the right line *cd*, for the course of the reflected ray D*c*; make also the angle CB*d*, equal to the angle DBC, and draw the right line B*d*, for the course of the reflected ray DB. All these reflected rays will meet in the point *d*, where they will form the extremity, *d*, of the inverted image, *e d*, similar to the extremity, D, of the upright object DE. If the pencil of rays, E *f*, E *g*, E *h*, be also continued to the mirror, and their angles of reflection from it be made equal to their angles of incidence upon it, as in the former pencil from D, they will meet at the point *e*, by reflection, and form the extremity *e*, of the image, *e d*, similar to the extremity, E, of the object, DE. As each intermediate point of the object between D and E, sends out a pencil of rays in like manner to every part of the mirror, the rays of each pencil will be reflected back from it, and meet in all the intermediate points between the extremities, *e* and *d*, of the image; and hence the whole image will not be at *i*, that is, at half the distance of the mirror from its centre of concavity C, but at a greater distance between *i* and the object DE; and the image will be inverted with respect to the object. Thus it is, that when the object is more remote from the mirror than its centre of concavity C, the image appears less than the object, and between the object and the mirror; contrary to what is observed when the object is nearer than the centre of concavity, as in the example of the face looking at itself, fig. 9, pl. III. If DE, fig. 10, be the object, *e d* will be its image; for as the object recedes from the mirror, the image approaches nearer to it, and as the object approaches nearer to the mirror, the image recedes further from it, on account of the less or greater divergency of the pencils of the rays which proceed from the object; for the less they diverge, the sooner they are converged to points by reflection; and the reverse necessarily follows, that the more they diverge, the further they must be reflected before they meet. If the radius of the mirror's concavity and the distance of the object be known, the distance of the image from the mirror is found by this rule: Divide the product of the distance and radius by double the distance made less by the radius, and the quotient is the distance required. If the object be in the centre of the mirror's concavity, the image and object will be coincident and equal in bulk.

If a man place himself directly before a large concave mirror, but further from it than its centre of concavity, he will see an inverted image of himself in the air, between him and the mirror, of a less size than his own person. If he hold out

his hand towards the mirror, the hand of the image will come out towards his hand, and coincide with it, of an equal bulk when his hand is in the centre of concavity; and he will imagine he may shake hands with his image. If he reach his hand further, the hand of the image will pass by his hand, and come between it and his body; and if he move his hand towards either side, the hand of the image will move towards the other; so that whatever way the object moves, the image will move the contrary way. A by-stander will see nothing of the image, because none of the reflected rays that form it enter his eyes.

From this remarkable property of a concave mirror to form an image in the air, mirrors of this sort are used to produce a variety of singular appearances, to amuse the curious, or to impose upon the ignorant and superstitious. To a few we shall give a place. If a fire be made in a large room, and a smooth mahogany table be placed at a considerable distance near the wall, before a large concave mirror, so situated that the light of the fire may be reflected from the mirror to its focus upon the table; if a person stand by the table, he will see nothing upon it but a longish beam of light; but if he stand at a distance towards the fire, not directly between the fire and the mirror, he will see an image of the fire upon the table, large and erect. If another person, who knows nothing of the experiment beforehand, should chance to come into the room, and should look from the fire towards the table, he would be startled at the appearance; for the table would seem to be on fire. In this experiment, there should be no light in the room, but what proceeds from the fire; and the mirror ought to be at least fifteen inches in diameter.

If the fire used in the last experiment be extinguished or covered by a screen, and a large candle be placed in a similar position, a person standing by the candle will see the appearance of a star, or rather planet, upon the table, as brilliant as Venus or Jupiter in a cloudless sky. If a slender wax taper be placed near the candle, a satellite to the planet will appear on the table; and if the taper be moved round the candle, the mimic satellite will go round the planet.

Another experiment is the following: Take a glass bottle, partly fill it with water, and cork it in the common manner; place this bottle opposite a concave mirror, and beyond its centre of concavity, that it may appear reversed; let the spectator retire to a still greater distance than the bottle, which he will then see in the air inverted, and the water which is actually in the lower part of the bottle, will in the image appear uppermost. Invert the bottle whilst before the mirror,

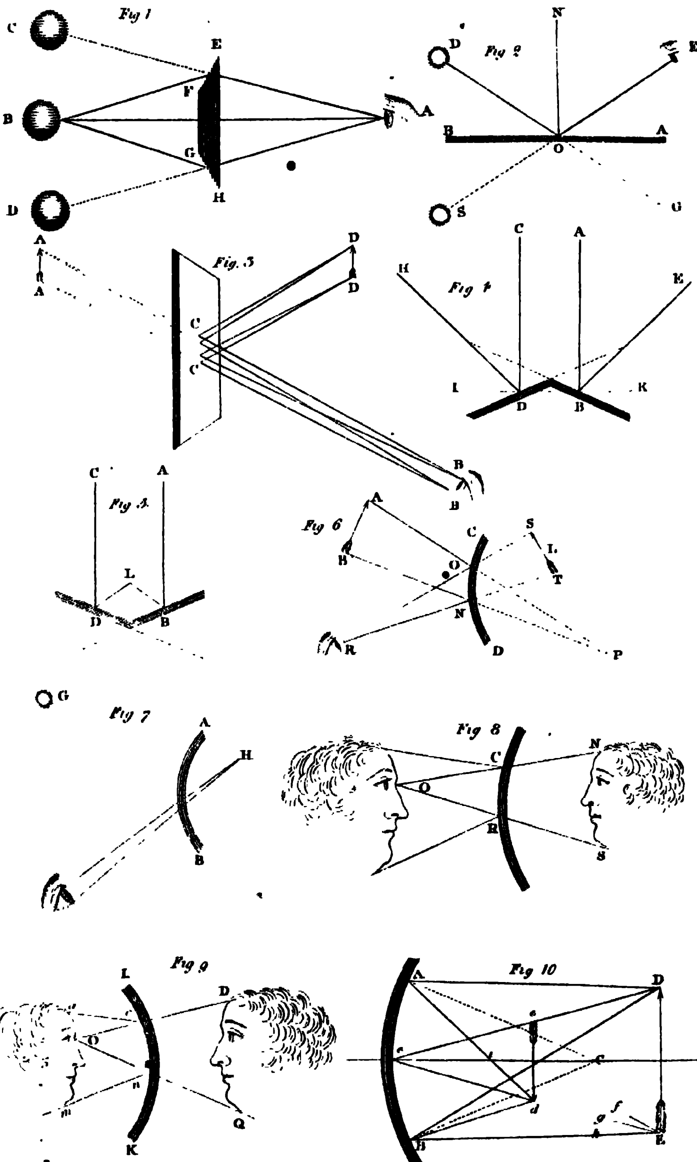
and in the image the water will appear in the lower part of the bottle: when it is in this inverted state, uncork the bottle, and whilst the water is running out, the image will appear to be filling; but as soon as the bottle is empty, the illusion ceases.

As the image formed by a concave mirror may be thrown through a hole into an adjoining room, where a spectator will in certain situations perceive the image of any object the concealed manager may chuse, it is evident how much the credulous may be imposed upon. Birds, angels, &c. may be represented flying, and may be instantly changed for other objects. A nosegay may be shewn, and when the beholder attempts to grasp it, a dagger, with all the appearance of reality, may be presented to his breast, or a death's head snap at his hand.

To find the focal distance of a convex mirror or speculum, cover it with paper containing two pin-holes, one near each edge of the mirror; expose it to the sun, holding another paper before it that has a hole large enough to let the solar rays pass through to the two pin-holes. Two white spots of reflected light will be observed on each side of the hole; move the paper backwards and forwards, till the distance of the spots be twice the distance of the holes in the cover; and that distance of the paper from the cover is its focus.

To find the focal distance of a concave speculum, place it so that its axis may be directed to the centre of the sun. Find the burning point, or receive the image upon a white piece of paper, and the distance thus found between the paper and the centre of the speculum, is the focal length. Or, cover the mirror with paper, in which make two or more holes, and observe where the beams of light reflected from these holes unite, and this will be the focal distance. Or, lastly, place the speculum at the end of a long table, in a vertical position; place a candle at the opposite end of the table, so that its flame may be opposite to the axis of the speculum; then take a piece of white paper, and having fixed it to a stick, place the stick in the socket of a candlestick, so that the paper may be supported at about the same height with the candle; then move the paper or the candle forwards or backwards, till the image of the candle on the paper is exactly over the candle itself, and the point of coincidence is the centre of the speculum.

For purposes of amusement, mirrors are frequently made in the form of entire or half cylinders or cones. These are called mixed mirrors, as they produce, at the same instant, the effects of plain and spherical mirrors. The properties of cylindrical mirrors are, 1. The dimensions of objects corresponding length-



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Published by Henry Fisher, Caxton, London, 1822

wise to the mirror, are not much changed; but those corresponding breadthwise have their figure altered, and their dimensions lessened, the further they are from the mirror, whence arises a very great distortion. 2. If the plane of the reflection cut the cylindrical mirror through the axis, the reflection is performed in the same manner as in a plane mirror; and if parallel to the base, the reflection is the same as in a spherical mirror; if it cut it obliquely, the reflection is the same as in an elliptic mirror. Hence, as the plane of reflection never passes through the axis of the mirror, except when the eye and the object are in the same plane; nor parallel to the base, except when the radiant point and the eye are at the same height; the reflection is therefore usually the same as in an elliptic one. 3. If a *hollow* cylindric mirror be directly opposed to the sun, instead of a focus of a point, the rays will be reflected into a lucid line parallel to its axis, at the distance of about one-fourth of its diameter.

Conical mirrors produce a still more extraordinary distortion of the figures seen in them than cylindrical ones, from the breadth of the image being gradually reduced as it approaches the apex, where it becomes a mere point. The effect of a cylindrical mirror in diminishing the breadth of objects facing it, being the same as that of a convex mirror of the same radius, and the effect of the conical mirror, at any given height, being regulated by the same principle, it becomes easy to draw anamorphoses for a cylindrical or conical mirror of any size. The pictures called by this name, and which are sold with mixed mirrors by the opticians, appear excessively wild and deformed to look at, but when placed before the mixed mirror for which they are intended, their images are well proportioned and beautiful.

Of the different Refrangibility of the Rays of Light.

The different refrangibility of the rays of lights, which we have now to consider, is demonstrated by means of the prism, a name which opticians give to a solid piece of glass, of any length at pleasure, but of a wedge-like or triangular form. As any section of a prism, passing through its axis, is a triangle, it is always represented by a triangle, which may be considered as shewing correctly one of its ends, see fig. 12, No. 8, pl. II.

If a beam of light from the sun be let into a darkened room, and be received upon a white screen or opposite wall, it will form a circular image, and will be of one uniform whiteness. If a prism be interposed, so that the light must pass through it before it reaches the wall, the image is no longer circular and

no longer white. It assumes an oblong shape, terminated by semicircular arches, and exhibits seven different colours. This oblong image is called the spectrum, and from its being produced by the prism, the prismatic spectrum. In the compass of philosophical experiment, a more beautiful appearance cannot be presented to the eye; and its instructive nature will appear not less extraordinary than its beauty, when it is considered, that the investigation of the cause of it, led Sir Isaac Newton to form the first rational theory of the cause of colours. The manner in which this illustrious philosopher tried the experiment of the spectrum, is described by himself in the following words, which remain to this day, perhaps, the most suitable introduction to this subject:

"In a very dark chamber, at a round hole, F, fig. 1, pl. IV, about one-third of an inch broad, made in the shutter of a window, I placed a glass prism, ABC, whereby the beam of the sun's light, SF, which came in at that hole, might be refracted upwards, toward the opposite wall of the chamber, and there form a coloured image of the sun, represented at PT. The axis of the prism (that is, the line passing through the middle of the prism, from one end of it to the other end, parallel to the edge of the refracting angle) was in this and the following experiments, perpendicular to the incident rays. About this axis I turned the prism slowly, and saw the refracted light on the wall, or coloured image of the sun, first to descend, and then to ascend. Between the descent and ascent, when the image seemed stationary, I stopped the prism, and fixed it in that posture. Then I let the refracted light fall perpendicularly upon a sheet of white paper, MN, placed at the opposite wall of the chamber, and observed the figure and dimensions of the solar image, PT, formed on the paper by that light. This image was oblong, and not oval, but terminated by two rectilinear and parallel sides and two semi-circular ends. On its sides it was bounded pretty distinctly, but on its ends very confusedly and indistinctly, the light there decaying and vanishing by degrees. At the distance of 18½ feet from the prism, the breadth of the image was about 2⅛ inches, but its length was about 10¼ inches, and the length of its rectilinear sides about eight inches; and ACB, the refracting angle of the prism, whereby so great a length was made, was 64 degrees. With a less angle, the length of the image was less, the breadth remaining the same. It is farther to be observed, that the rays went on in straight lines from the prism to the image, and therefore, at their going out of the prism, had all that inclination to one another from which the length of the image proceeded. This image PT was

coloured, and the more eminent colours lay in this order from the bottom at T to the top at P; red, orange, yellow, green, blue, indigo, violet, together with all their intermediate degrees, in a continual succession, perpetually varying."

If the spectrum be divided into 100 parts, the red part of it is found to occupy 11 of these parts, the orange 8, the yellow 14, the green 17, the blue 17, the indigo 11, and the violet 22. The red part of the spectrum, it will be observed, is nearest the prism, and the violet at the greatest distance. It is clear, therefore, that light is not homogeneous, because the attractive power of the prism has been greater upon some parts of it than upon other parts. Accordingly, it is universally concluded, that the solar beam, or white light, is composed of particles differing in size or density; that this difference of their size or density, is the cause of their being differently refrangible, and that the separation of the rays of one or more sizes from the rest, by various means, produces all the diversity of colours which affect our sight.

We find the red part of light capable of struggling through thick and resisting mediums, when all the other colours are stopped. Thus the sun appears red when seen through a fog; the light of distant lamps seen through the smoke of a long street, appears red, while the light of those at hand is white. Dr. Halley's hand appeared red in the water, when he was in a diving-bell at the bottom of the sea, and red light always makes the strongest impression on the eye. These are all proofs, that red light consists of particles which are larger than those of other colours, and which having therefore the greatest momentum, are the least disturbed by the action of a given force, so that they necessarily take a shorter course than other rays in passing through the prism. The particles which compose orange light, are next in size and refrangibility to the red, and so on to the violet, which consists of the smallest sized particles, and they are therefore the most turned out of their course.

The seven colours of the spectrum, are called the original or primary colours. White is composed of them all mixed together in their due proportions; for if a solar ray, separated by the prism into its component parts, be collected and converged into a focus by a lens or a conçave mirror, a paper placed perpendicularly in this point will exhibit a white spot. The same conclusion may be drawn from the experiment of mixing together paints of the same colours as the parts of the spectrum, and in the same proportion; the mixture will be white, though not a resplendent whiteness, because the colours mixed are less bright than the primary ones, and because they

cannot be intimately blended without exercising a chemical action on each other, which in part changes their properties. When this action is prevented, the result of the experiment is much more satisfactory: the rim of a wheel may either be painted or covered with pieces of cloth, &c. of all the seven colours in due proportion, and if it be then swiftly turned upon its axis, it will appear to be white. Supposing the wheel to be divided into 360 equal parts, the red should occupy 45 of these parts, the orange 27, the yellow 48, the green 60, the blue 60, the indigo 40, and the violet 80.

It may be supposed that the seven primary colours may be reduced to three, viz. red, blue, and yellow, because of these three all the rest might be made. It is necessary therefore to explain the sense in which it is understood that there are seven primary colours. None of the colours thus named can be changed by any art, or whatever number of refractions or reflections they undergo. Let a hole be made in the paper or screen receiving the prismatic spectrum, at the place covered by the green rays; if these rays be refracted through fifty prisms, and as often reflected from mirror to mirror, they still retain their greenness: hence we are compelled to consider the green rays as composed of simple homogeneous particles, consequently one of the primary colours; and the same may be said of any other colour, which might be supposed to be compound.

When any coloured body is placed in homogeneous light, it always appears of the colour of the light in which it is placed, whatever may be its natural hue; thus, if prussian blue and vermilion he placed in a red light, both will appear red; in a green light, green; in a blue light, blue; &c. It is, however, to be allowed, that a body appears brighter when in a light of its own colour than in another; and from this we may see that the colours of natural bodies arise from an aptitude in them to reflect some rays more copiously and strongly than others. But lest this phenomenon should produce a doubt of the constancy of the primary colours, it is proper to assign the reason of it, which is this: that when placed in its own coloured light, the body reflects the rays of the predominant colour more strongly than any of those intermixed with it; therefore the proportion of the rays of the predominant colour to those of the others, in the reflected light, will be greater than in the incident light; but when the body is placed in a light of a different colour from its own, for a similar reason, the contrary effect will follow, that is, the proportion of the predominant colour to the others will be less in the reflected than in the incident light; and therefore as its splendour would be

greater in the former case, and would be less in the latter, than if all the rays were equally reflected, the splendour of the predominant colour will be much greater in the former case than in the latter.

When bodies either reflect all the rays of light which they receive, or reflect them in the proportion in which they exist in the solar beam, they appear white; when they reflect none of the rays, they appear black. Between perfect white and perfect black, innumerable species of colours may be formed by different combinations of the rays, under different influences of reflection or transmission.

When the expressions, red rays, yellow rays, &c. are used, it is not to be understood that the rays themselves possess any property analogous to what we call colour, but merely that they have the power of exciting in us the sensations which we call redness, yellowness, &c. They would, therefore, with more correctness, be called *red-making* or *red-causing* rays, *yellow-making* or *yellow-causing* rays, &c. but the frequent recurrence of this precision would be as awkward as it is unnecessary.

Of the Rainbow and other natural Phenomena dependent upon the Refrangibility of Light.

Of the natural phenomena produced occasionally by the separation of the primary colours, the rainbow is one of the most beautiful. This meteor, which in poetical language is called the *iris*, never makes its appearance, except when the spectator is situated between the sun and a shower of rain; hence we conclude that it is occasioned by the sun and the drops of rain; and that this conclusion is just, any one may satisfy himself by the following experiment: Fill a hollow glass globe with water, and suspend it in the sun, in such a manner that it may be raised or lowered at pleasure; at a certain height above the eye of the spectator, who looks at it with his back to the sun, the globe will appear to be red; let it then be slowly lowered, and it will appear to be orange, and afterwards in succession, as it descends, it will appear yellow, green, blue, indigo, and violet. Hence the same drop of rain, which must be considered as a little globe, supplies all the seven colours to the eye, just as they would be supplied if, in trying the experiment of the spectrum, the operator were to remove the paper MN, fig. 1, pl. IV, and to place his eye so that it would receive the red rays, when, if he gradually raise himself, or lower the aperture for the light and the prism together, he would perceive all the other colours in succession.

There are sometimes two rainbows seen at the same time,

one within the other, and, what may seem remarkable, the order of the colours of the exterior bow is the reverse of that of the interior one. When two bows are seen, the exterior one is comparatively faint, and is therefore sometimes called the false or secondary bow, while the greater distinctness of the interior one has obtained for it the appellation of the primary bow. To trace the progress of a ray of light through a drop of rain in each of these bows, will explain the cause of their differing in brightness.

In the true or primary bow, the rays of light arrive at the spectator's eye after two refractions and one reflection. Thus, let A, fig. 2, pl. IV, be a drop of rain, and S*d* a ray from the sun falling on the upper part of the drop at *d*. It will suffer a refraction, and instead of going forward to *c*, it will be bent to *n*; at *n*, part of it will emerge, but the remainder will be reflected to *g*; at *g* it will be again refracted on passing into the air towards the eye at *h*; by being thus twice refracted and once reflected, the ray is separated into its primitive colours; the red part, which is least thrown out of its course, makes an angle, at its emergence, with the incident solar ray of forty degrees two minutes, as S*f g*; and the violet, being the most easily thrown out of its course, makes with the solar light an angle of 40° 17′, as S *c g*. The different colours, therefore, at the distance of the spectator, are considerably separated, and affect the eye in succession with the seven colours; but the succession is so quick, and so many drops fall through the same circuit in the same time, that the mind loses the idea of succession, and the bow seems permanent as long as the shower continues in a proper direction from the eye.

The exterior or secondary bow is formed by two reflections and two refractions. Let B represent one of the drops of rain forming this bow; a ray, T, from the sun, falling upon it at *r*, is refracted, and falls upon the back of the drop at *s*; at *s*, from the transparency of the drop, a portion of it passes through towards *w*, but the remainder of it is reflected towards *t*; here again, for the same reason as before, part of it emerges from the drop, in the direction *x*, but the portion still left is reflected to *u*, where it is refracted towards the spectator, with the red rays uppermost. The great quantity of light lost at each reflection, is the cause of the indistinctness of this bow, and therefore we cannot be surprised that we rarely, if ever, see bows formed by a still greater number of reflections within the drops; for though they may exist, they are too faint to be seen. The secondary bow cannot be seen when the elevation of the sun is above 54° 7′; it is broader than the interior bow, because the rays are more dispersed before they reach the eye.

When the spectator is upon a plain, and the sun is close to the horizon, the rainbow is a semi-circle; but according as the sun is higher above the horizon, so the rainbow is a smaller part of a circle. When the spectator is upon an eminence, and the sun is near the horizon, then the rainbow may exceed a semicircle; and from a great elevation, a complete circle may be perceived. In all cases, the centre of the bow, the spectator, and the sun, must be in the same straight line, which is called the *line of aspect*. The sun may therefore be considered as the vertex of a cone, whose base is the rainbow, and whose axis constitutes the line of aspect. If several people are standing together, they each see a different rainbow, because they are each in the axis of a different cone. Hence the bow moves as the spectator moves, but other drops in another circle producing the same effect, the change is not perceived. The bow assumes a circular form, because it can only be seen by rays which form the same angle with the line of aspect. The primary bow can never be seen, if the sun be elevated more than 42° 2′ above the horizon.

Lunar rainbows are sometimes observed, but the faintness of the moon's light, compared with that of the sun, is the reason that their colours can very rarely be distinguished.

When the sun and the eye of the spectator are properly situated, drops of water produce the phenomenon under a variety of other circumstances. A bow with its convex side towards the spectator, is sometimes seen on the ground, when the sun shines on a very thick dew; also at waterfalls, and at sea, when part of the agitated water is dispersed in drops, the bow is seen in its usual form. Water blown violently from the mouth of an observer, will also produce a miniature iris, and by means of a small fountain, an artificial one may be shewn by candle-light.

The diversified colours of the sky under different circumstances, are also accounted for on the principle of the different refrangibility of the rays of light. When the sun is near the horizon, as in the morning and evening, the vast tract of dense and vaporous air in a direct line from him to the earth, produces the absorption of the weaker rays, and therefore the clouds reflect only the vivid yellow, the orange, and the red. As the quantity of the vapours, and even their nature, are not similar for two days together, this irregularity produces corresponding differences in their effects. Terrestrial objects, and even the sun himself, are necessarily tinged like the light by which they are seen. When the light at these times is received by a prism, it is found that the rays actually absorbed are such as we should expect to be so from the coloration of the

moment. In consequence of the successive increase and density of the vapours traversed by the light, clouds differently placed, are at the same instant tinged of different colours. The highest may even be white, while the rest, at a less elevation, will be yellow, and others still lower will be red, or approach nearly to red. At an equal elevation, the most distant from the point where the sun sets, will incline to red, and the nearest to yellow.

A luminous circle, called a halo or corona, is frequently observed to surround the sun, moon, and even the planets and stars. It is sometimes coloured, but generally white. It is attributed to the effects produced on the light of these bodies, in passing through dense clouds, or a frozen medium of hail or snow, and it is white or coloured, according as the rays have undergone a prismatic separation or not. The parhelia, or mock suns, which are sometimes observed, are referable to a similar origin.

To the thinking mind, it cannot but be interesting to observe, in how many instances the causes of phenomena which were formerly considered as altogether inexplicable, and regarded with superstitious dread, are now familiar to children, and allusions to them assimilated with the language of poetry. They are no longer considered as the ominous harbingers of evil; they are produced for amusement by experiment, and when they occur under natural circumstances, are contemplated with delight, because they are known to be the result of those immutable laws which the Author of nature has assigned for the government of his works. Optical science furnishes several illustrations of this subject, and we shall mention one which is not the least remarkable, from its connection with historical events. A day or two before the massacre of St. Bartholomew, Henry IV. of France (then a prince at the court of Charles IX, and not implicated in the guilt of that massacre,) sat down to dice with the Duke of Guise, and just as they were going to play, he perceived what he supposed to be drops of blood Attempts were made to wipe these drops away, but they still returned, or new ones were seen in their places. The strictest examination was made among the spectators, yet it could not be discovered whence the drops proceeded. This event made so strong an impression upon the mind of Henry, that he alluded to it in the memorable speech he delivered to his parliament, not less than 27 years afterwards: "I," says he, "looked upon it as a dismal omen, and rising up from play, I turned aside, and said to some of my particular friends, that I foresaw much blood would be shed." From the best evidence that history affords us of this event, we can collect but little in

formation of the circumstances of the moment; but black, as the black spots of the dice, may be so completely changed into scarlet, that we cannot at this day consider the appearance of the blood-spots as any thing more than the accidental occurrence of a natural phenomenon. Let any person take a book, and standing in the strong light of the sun, which must fall upon his eyelids, but not upon the book, let him look steadily at the printing, and he will soon see the blackness of the letters changed to the hue of vermillion.

This appearance is of easy explanation; it is well known, that when we turn our eyes to the sun, with our eyelids closed, we have the sensation of a lively red. Now the eyes, which are covered with respect to the sun by the eyelids, are open to the book, and consequently the white of the paper, which reflects so much light, makes upon the retina an impression sufficient to erase the impression of the red rays in all the points of the retina upon which the white rays fall. The black letters, on the contrary, which are printed on the white paper, send back few or no rays to the bottom of the eye, and consequently all the points of the retina, on which, in other cases, they are depicted black, preserve in all their vigour, the first impression of red which had been made by the sun upon the whole retina. The circumstances, essential to the production of this illusion, are, 1. the sun's shining upon the eyelids; 2. the rays of the sun not falling upon any of the black spots; 3. the sun's having shone for at least two minutes upon the eyelids.

Of the Inflection and Deflection of Light.

The refraction of light, we have seen, is attributed to a power of attraction appertaining to all bodies, and exerted at a little distance from their surfaces; reflection, on the contrary, is produced by a power of repulsion, and also takes effect before the light actually strikes the reflecting surface. If these attractive and repulsive energies have any real existence, the rays of light, under certain circumstances, will be bent, in a manner that cannot be classed under either refraction or reflection. Accordingly, we find, that if a ray of light pass very near a body, without impinging upon it, it is bent inwards, or towards the body; this change in the direction of the ray, is called *inflection.* If the ray pass at a greater distance, it is bent out wards, or from the body; this change in the direction of the ray, is called *deflection.*

When a beam of the sun's light passes through a hole in a window shutter, the image thrown upon a screen or an opposite wall, is larger than it would be if the rays, crossing at the aper-

ture, proceeded in straight lines from the circumference of the sun's disk to the wall. It becomes therefore an object of inquiry, to determine the cause by which it has been expanded; and we find, on close examination, that the side of the aperture has inflected or caused to diverge from the axis of the beam, the rays which have passed near it all around.

Inflection was first discovered by Grimaldi, who made many curious experiments and observations relative to it; but the following experiments of Sir Isaac Newton, will be better adapted than Grimaldi's to explain the nature of this property of light. At the distance of two or three feet from the window of a darkened room, in which there was a hole three-fourths of an inch broad, to admit the light, he placed a black sheet of pasteboard, having in the middle a hole about a quarter of an inch square, and behind the hole the blade of a sharp knife, to intercept a small part of the light which would otherwise have passed through the hole. The planes of the pasteboard and blade were parallel to each other, and when the pasteboard was removed to such a distance from the window, that all the light coming into the room must pass through this hole in the pasteboard, he received what came through the hole on a piece of paper two or three feet beyond the knife, and perceived two streams of faint light shooting out both ways from the beam of light into the shadow. As the brightness of the direct rays obscured the fainter light, by making a hole in his paper, he let them pass through, and had thus an opportunity of attending closely to the two streams, which were nearly equal in length, breadth, and quantity of light. That part which was nearest to the sun's direct light, was pretty strong for the space of about a quarter of an inch, decreasing gradually till it became imperceptible, and at the edge of the knife it subtended an angle of about twelve or at most of fourteen degrees.

Another knife was then placed opposite to the former, and he observed, that when the distance of their edges was about the four-hundredth part of an inch, the stream divided in the middle, and left a shadow between the two parts which was so dark, that all the light passing between the knives seemed to be bent aside to one knife or the other; as the knives were brought nearer to each other, this shadow grew broader, till upon the contact of the knives the whole light disappeared. He observed also, fringes of different coloured light, three made on one side by the edge of one knife, and three on the other side by the edge of the other.

Grimaldi, Dr. Hooke, and all the philosophers who made experiments on inflection before the time of Newton, ascribed the broad shadows, and even the fringes which he mentions, to the

ordinary refraction of the air; but the investigation upon which he entered to discover their cause, afforded him satisfactory evidence to conclude that bodies have the power of acting upon light at a distance.

The Philosophical Transactions for 1796, contain a paper by Henry Brougham, F. R. S., detailing one of the most valuable series of experiments on the mechanical properties of light, which has appeared since the time of Newton. It had been generally supposed that the parts of which light consists, have all the same disposition to be acted upon by bodies which inflect, deflect, and reflect them; but he soon proved that this opinion was erroneous. Having admitted into a darkened chamber, a beam of the sun's light through a hole in a metal plate (fixed in the window shutter) of $\frac{1}{30}$th of an inch in diameter; and all other light being absorbed by black cloth hung before the window and in the room, at the hole he placed a prism of glass, whose refracting angle was 45 degrees, and which was covered all over with black paper, except a small part on each side, which was free from impurities, and through which the light was refracted, so as to form a distinct and tolerably homogeneous spectrum on a chart at six feet from the window. In the rays, at two feet from the prism, he placed a black unpolished pin, one-tenth of an inch in diameter, parallel to the chart, and in a vertical position. Its shadow was formed in the spectrum on the chart, and had a considerable penumbra, especially in the brightest red. It was by no means of the same thickness in all its parts; in the violet it was broadest and most distinct; in the red it was narrowest and most confused, and in the intermediate colours it was of an intermediate thickness and degree of distinctness. It was not bounded by straight, but by curvilinear sides, which were concave outwardly. This figure of the shadow was not owing to any irregularity in the pin, for the same thing happened with all sorts of bodies that were used; and also if the prism was moved on its axis, so that the colours might ascend and descend on these bodies, still, wherever the red fell it made the least, and the violet the greatest shadow. In the next place, he fixed a screen, having in it a large hole on which was a brass plate, pierced with a small hole of $\frac{1}{42}$ of an inch in diameter; then causing an assistant to move the prism slowly on its axis, he observed the round image made by the different rays passing through the hole to the chart; that made by the red was greatest, by the violet least, and by the intermediate rays of an intermediate size. Also, when at the back of the hole he held a sharp blade of a knife, so as to produce the fringes mentioned by Grimaldi and Newton, those fringes in

the red were broadest, and most moved inwards to the shadow, and most dilated when the knife was moved over the hole; and the hole itself on the chart was more dilated during the motion when illuminated by the red, than when illuminated by any other of the rays, and least of all when illuminated by the violet. From these, and a great variety of other experiments, well devised and often repeated with rigorous care, he infers, that the rays of light are separable into their primitive colours, by inflection, deflection, and reflection, as well as by refraction; that the flexibilities and reflexibilities of the rays are inversely as their refrangibilities; that is, those which deviate the least by refraction, deviate the most by flection, and are reflected the furthest from the perpendicular; and that the different flexibilities, reflexibilities, and refrangibilities of the rays, are all produced by the differences in the magnitude of the particles. He calculates that the size of the red particles are to those of the violet as 1275 to 1253. This he extends to all the other colours by similar calculations, their sizes lying between 1275 and 1253; which are the extreme red and extreme violet; the red therefore is from 1275 to 1272½; the orange from 1272½ to 1270; the yellow from 1270 to 1267; the green from 1267 to 1264; the blue from 1264 to 1260; the indigo from 1260 to 1258, and the violet from 1258 to 1253. The whole paper is highly curious and deserving of attention, but it would be impossible to do it justice by analysis in our limits.

From the separation of light into its component parts, by inflection, we readily perceive how the coloured fringes of light thus influenced are produced; but other appearances derive their origin from inflection, where colour is not always observable. On looking at the printing of a book through a very small hole, such as the hole made by a needle in a piece of paper, the letters appear considerably magnified. In this case, the rays which form the image pass so near the circumference of the hole, as to be inflected by it, and they therefore form a larger picture on the retina than the direct rays would have done. When we look at a distant steeple, or any similar object, and intercept the direct rays from it by crossing the line of sight with a wire of rather less diameter than the pupil, held very near the eye, the object will be seen by rays bent inwards or inflected, which would otherwise not have entered the eye, and as they make a much larger angle, the object appears magnified.

When we look at a candle, or any other luminous body, with our eyes almost closed, streaks of light appear to dart upwards and downwards; if the head be reclined, the change in the direction of the streaks is correspondent. This appearance has

been most commonly attributed to the inflection of light passing between the eye-lashes; but it is most probable that inflection only occasions a very small part of it; and that the rest is produced by the refraction of light through the humours adhering to the eye-lids, because, as Brougham observes, the streaks which dart from the top of the luminous body are formed by the under eye-lid; or at least by the moisture adhering to the under ciliary process, and those which appear from the bottom of the body, by the upper eye-lid; which could not be, either if they were formed, as some have supposed, by reflection from the processes, or by inflection through the lashes.

Of the Eye and the general Phenomena of Vision.

The eye is an organ, not less admirable in its mechanical properties and structure, than invaluable for its use. To expatiate on its utility would be idle, to treat of its expression belongs to the physiognomist; it is our duty to explain merely the manner in which it performs its office. To this end we must first describe its several parts:

The eye is of a globular figure, rather protuberant in front, and is composed of three membranes called coats, and three pellucid substances called humours. Each coat and each humour has a different name. By fig. 3, pl. IV, is represented a section of the human eye. The part DHHG, of the outer coat, is called the *sclerotica*, the exterior part or continuation of it, DEFG, is called the *cornea*, from its resembling horn. The sclerotica is strong and unelastic, and the muscles which move the eye are attached to it. What is called the white of the eye, is a part of this coat. The cornea bulges out a little from the eye-ball; it is circular, and exceedingly transparent.

The next coat to the sclerotica is called the *choroides*, which serves as a lining to it. It is of a dark colour in the human eye, but white in cats and owls, and green in animals that live on grass and vegetables. Its texture is soft, and pulpy, and too weak to be susceptible of muscular motion, except at its extremities towards the front of the eye. Like the sclerotica, it is distinguished into two parts; the fore-part being called the *iris*, while the hinder part retains the name of the choroides. The iris commences immediately under the commencement of the cornea. It here attaches itself more strongly to the sclerotica by a cellular substance, forming a kind of white, narrow, circular rim, called the *ciliary circle*. The iris is that remarkable circle, which gives the eye its character as to colour; it is composed of two sets of muscular fibres; the

one tending, like radii, towards the centre of the circle, and the other forming a number of concentric circles round the same centre. The central part of the iris is perforated, and the aperture, which is called the *pupil*, is always round, but varied in diameter by the action of the two sets of muscular fibres composing the iris. When a very luminous object is viewed, the circular fibres contract, the radial are relaxed, and thus the size of the pupil is diminished; on the other hand, when the objects are dark and obscure, the radial fibres of the iris contract, the circular are relaxed, and the pupil is enlarged, so that it admits a greater quantity of light. By candle-light, the contraction and dilation of the pupil may be very distinctly observed, with the assistance of a looking-glass. If, with our eyes directed to the mirror, we bring the candle close to our face, we shall find the pupil become very small; if the candle be removed and completely shaded for about a minute, and then brought to its former place, it will be found that the pupil has greatly dilated, and that it again contracts as the light draws nearer; if the light shine much more strongly on one eye than the other, the pupil of the shaded eye will not contract so much as the other.

The whole of the choroide membrane is opaque, by which means no light can enter the eye but what passes through the pupil, but to render the chamber of the eye still darker, the posterior surface of this membrane is covered with a black mucus called the *pigmentum nigrum*.

Under the iris, there is a prolongation, *n n*, of the choroides, which forms a circular band of radial fibres, turning inwards towards the centre of the eye, and filled up between with a black mucus, giving it the appearance of a membrane. This circular band is called the *ligamentum ciliare*, or *ciliary ligament*.

The third and last coat of the eye is called the *retina*. This is a fine and delicate membrane, being an expansion of the optic nerve L, which proceeds from the brain. Its course is represented by dots in the figure; it is spread like a net of exquisite delicacy, all over the concave surface of the choroides, and terminates at the ciliary ligament *n n*. It receives the images of objects, which are depicted upon it by the rays of light that enter at the pupil. It is of itself transparent, and of an ash-coloured white, but appears black on account of the pigmentum nigrum behind it. The optic nerve, L, which passes through a small hole in the bony cavity containing the eye, and conveys to the sensorium the impressions made on the retina, is not in the centre of the eye, but a little on one side, inclining towards the nose.

The three transparent substances enclosed by the coats of the eye are called the *aqueous, crystaline,* and *vitreous humours.* The first of these, or aqueous humour, resembles water, whence its name. It gives a protuberant figure to the cornea, fills the two cavities *m m, n n,* between the cornea and ciliary ligament, which cavities communicate by the pupil P. The part *m m,* is called the anterior, and *n n* the posterior portion of the aqueous humour, the iris, which swims in it, constituting the division. The refractive power of the aqueous humour is like that of water.

The second, or crystalline humour, R, is, like the former, eminent for its transparency, which exceeds that of the purest crystal; it has the consistence of a hard jelly, growing somewhat softer from the middle towards the edges. Its form is that of a double convex lens, but more convex on the interior than the exterior surface. Resembling a lens in its form, it also resembles one in its use: it converges the rays which pass through it from every visible object to its focus on the retina. It is inclosed in a fine transparent cover, or membrane, called the *arachnoides,* which is attached to the *ligamentum ciliare* before mentioned; and by that means it is suspended. The radial fibres of the ligamentum ciliare, have the power of contracting and dilating occasionally, by which means they alter the shape or convexity of this natural lens, and shift it a little backwards and forwards in the eye, so as to adapt its focal distance from the retina to the different distances of objects. Without this or some equivalent arrangements, we should only see those objects distinctly that were at one distance from the eye.

At the back of the crystalline, lies the third or vitreous humour KK. It receives its name from its supposed resemblance to melted glass. It is not so hard as the crystalline, nor so liquid as the aqueous humour. It is by far the largest of all the humours in quantity, and gives the eye its globular shape. In its refractive power, it very little exceeds water; in consistence it is like the white of an egg.

As every point of an object, ZVX, sends out pencils of rays in all directions, some rays from every point on the side next the eye, will fall upon the cornea between EF, and by passing on through the pupil and humours of the eye, they will be converged to as many points on the retina, and will there form a distinct inverted picture BYA, of the object: for the pencil of rays flowing from the point Z of the object, will be converged to the point A of the retina; those from the point V will be converged to the point Y; those from the point X will be converged to the point B, and rays from all the interme-

diate points being converged in like manner, the whole image BYA is formed, and the object made visible.

With two eyes we not only see objects about one-thirteenth part brighter than when we use only one, but we see them in a different situation. Those who have lost the use of one eye are apt to mistake the distances of objects even within arm's length; and in such actions as the threading of a needle, or the snuffing of a candle, they do not succeed without considerable experience.

It has often been a subject of inquiry, why we see objects in their true position, though the image on the retina is inverted, but no satisfactory solution of the difficulty has ever been given. And we should be as likely to receive an answer, if we were to ask, why we do not perceive every object bent, because the image of it is depicted upon a concave surface. It is certain that unless distinct images are painted on the retina, objects cannot be clearly perceived. If from too little light, remoteness, or any other cause, a picture is indistinctly painted on the retina, an obscure or indistinct idea of the object is conveyed to the mind. The picture on the retina is therefore so far the cause of vision, that our ideas of visible objects vary as it varies, and when it is not formed, nothing is seen. Yet we may fairly conclude, that the mind does not look upon the image on the retina; for in cases of the gutta serena, a disorder which affects only the optic nerve, the pictures on the retina are as perfectly formed as in the best eyes, although the patient is afflicted with incurable blindness. It is the optic nerve, therefore, which conveys the impressions made on the retina to the brain, but how they are there communicated to the mind is screened from the view of man. It has been supposed that we acquire by experience the habit of seeing objects erect, but there are many striking facts to prove the contrary; persons who have been blind from infancy, and who have been suddenly restored to sight by a surgical operation, have not been led into the smallest mistake. In fact, no reason can be given why the mind should not perceive as accurately the position of bodies, when the rays reflected from the upper parts of those bodies fall upon the lower parts of the eye, as if the contrary took place.

To see an object distinctly, besides a sufficient quantity of light, it is necessary that the pencils of divergent rays which enter the eye, should converge to points on the retina. If the pencils fall in an unconverged state on the retina, the scattered state of the light causes it to make an indistinct impression, which may arise from two causes: 1. The rays

may require a greater distance than the size of the eye admits of, before they can be converged; and, 2. they may converge before they reach the retina, in consequence of which they will fall upon it in a dispersed state, because they have crossed and begun to diverge. Persons having the former defect, are called long-sighted, as they can frequently see objects at a great distance better than those near at hand. The reason is, that from age and infirmity, the cornea and crystalline lens become flatter, and consequently incapable of converging the rays so soon to points; and the defect is further increased, and may sometimes perhaps be wholly occasioned, by the ciliary ligament becoming either too flaccid or too rigid, to produce the various adjustments necessary to view objects at different distances. When the pencils of rays are converged to points before they reach the retina, the persons subject to the visual defect thence arising are said to be short-sighted, because they can only see those objects distinctly which are very near their eyes. The subject of long and short sightedness will be resumed, when we treat of spectacles; here we shall only further observe, that the eye is as much under the dominion of habit as any of our senses, and when long inured to one class of objects, becomes less fit for all others. The engraver, who is constantly employed in viewing objects near at hand with great attention, loses much of the facility of discerning objects at a distance; but the sailor, who never, perhaps, strains his eyes, except at distant objects, becomes less capable of seeing distinctly those which are near at hand.

The advantages of having two eyes, even so far as we are acquainted with them, are not confined merely to improving the brightness of objects, and shewing them in their true places. In each eye there is a spot where no vision takes place, and this spot, which is about the fortieth of an inch in diameter, lies exactly upon the insertion of the optic nerve, so that we cannot perceive the image of any object that falls upon it at the hinder part of the eye, provided the other eye be shut; but as the insensible parts of the two eyes are on the sides next each other, that part which is invisible to one eye, is visible to the other, and therefore the whole is seen. To be satisfied of the existence of such a spot, the following experiment may be resorted to. Let three pieces of paper be fastened upon the side of a room, about two feet asunder; and let the person place himself opposite to the middle paper, and beginning near to it, retire gradually backwards, all the while keeping one of his eyes shut, and the other turned obliquely towards that outside paper which is towards the covered eye, and he will find a situation, (which is generally

about five times the distance at which the papers are placed from one another,) where the middle paper will entirely disappear, while the two outermost continue plainly visible; because the rays which come from the middle paper will fall upon that part of the retina where the optic nerve enters. Hence it is evident, that if the optic nerve had not been inserted on one side, the centre of our field of view would have been invisible.

We have previously had occasion to mention the visual angle, and to intimate that the larger it was, the greater the apparent magnitude of any object beheld. The meaning of this expression will now be apparent, from the description we have given of the eye; but to render it still more evident, we shall refer to a figure. Let AB, fig. 4, pl. IV, be an object viewed by the eye QR. From each extremity draw the lines AN and BM, intersecting each other in the crystalline humour at I. Then draw the line IK, in the direction in which the eye is supposed to look at the object. The angle AIB is then the optical or visual angle, and the line IK is called the *optical axis*, because it is the axis of the lens or crystalline humour continued to the object. The apparent magnitude of objects, then, depending thus on the angle under which they are seen, must evidently vary according to their distances. Thus different objects, as AB, CD, EF, the real magnitudes of which are very unequal, may be situated at such distances from the eye as to have their apparent magnitudes all equal; for if they are situated at such distances, that the rays AN, BM, shall touch the extremities of each, they will then all appear under the same optical angle, and the diameter MN, of each image on the retina will consequently be equal. In the same manner, objects of equal magnitude, situated at unequal distances, will appear unequal. For let AB and GH, be two objects of equal size, placed before the eye at different distances, IK and IS; draw the lines GP and HO, crossing each other in I; then OP, the image formed by the object GH on the retina, is evidently of a greater diameter than the image MN, which represents the object AB; in other words, the object GH will appear as large as an object of the diameter TV, situated at the same place as the object AB.

When we look from one end towards the other of a long and straight row of houses or trees, they appear gradually to diminish as they are further removed from the eye, though upon a nearer inspection they are all found to be of equal size. It will be evident, from the observations we have just made respecting the visual angle, that this must be the case; for the

angle under which similar objects are seen, and consequently the evidence which sight affords us of their magnitude, is in an inverse proportion to the distance of those objects. The apparent exceptions to this rule apply to objects where the evidence of sight is corrected by the judgment. When objects are near, we do not judge of their magnitude according to the visual angle. Though a man six feet high is seen, at the distance of six feet, under the very same angle as a dwarf only two feet high, at the distance of two feet, still the dwarf does not appear as large as the man, because we are instantly able to make the requisite allowance for the difference of distance.

But when the distance is considerable, and we have no opportunity of comparing one object with another, we soon perceive that the rule just laid down has its foundation in nature. When Denon first drew near the gigantic pyramids of Gizeh, he was not particularly struck with their magnitude, principally because there were no objects in the vicinity by which a comparison could be made; but this impression was speedily effaced, when he had observed a hundred people who had preceded him assembled at the base of one of them, the deception instantly vanished, a comparison was formed, and the stupendous pile assumed all its appropriate majesty.

As an image of every visible object is painted on the retina of each of our eyes, we may be inclined to inquire, why we do not see every object doubled? Of the various opinions which have been advanced in explanation of this difficulty, the most satisfactory is, that in the two eyes there are corresponding parts of the retinas, which are probably susceptible of the same impression in equal degree, and convey it to the sensorium in that equal degree; hence, as long as similar points of the images fall upon the corresponding points of the retinas, the perception of the same object is single, otherwise it is double. It is a confirmation of this theory, that when a person, whose sight is perfect, looks with both eyes at an object straight before him, the axes of both eyes are inclined towards each other in equal degrees, and directed to the same point. In this case the images are formed upon the corresponding parts of the retinas, and in all other cases, the eyes move in unison, to produce the same effect; but while the same object still continues to be regarded, let the position of one eye be varied a little by a slight pressure of the finger, and the object will instantly appear double. Now the aberration of the axis of one eye, which is thus effected for a moment by design, is often produced by disease or habit, so that the power of directing both eyes to the same point is permanently lost: when this is the case, the person is said to *squint*, and the squint-eyed always see objects

double, unless they have acquired the habit of entirely disusing the eye of whose motion they have lost the natural and perfect command. No method of curing this defect, when it has not been absolutely irremediable, has been more successful than that of binding up for a time the sound eye, by which means the other is obliged to perform its office.

The nearer any object is, when viewed with two eyes, the greater the inclination of the axes of the eyes to each other, and the converse necessarily follows, when we take a distant view. It is by this adjustment that we are materially assisted in judging of the distances of objects not very remote, and that we know whether a person is looking at us or not.

We acquire also the habit of almost involuntarily taking into consideration a variety of other circumstances, in judging of distances. When objects appear obscure or confused, we judge them to be remote; and when they appear distinct, we form a contrary opinion: of these principles painters sedulously study to avail themselves. Rooms, the walls of which are whitened, appear smaller than when of a dark colour; fields covered with snow, or white flowers, appear less than when clothed with grass; mountains covered with snow appear nearer than at other times; and in the evening, when it is nearly dark, an upright post half white and half black, may be taken for a body of considerable size in horizontal extension.

An Englishman, when he first views an Italian landscape, makes the most egregious mistakes, in estimating the distances of places and objects by the eye. He has no conception of the clearness of the air, in that delightful climate, by which he is enabled to perceive objects at the distance of twenty miles, with so much distinctness, that he supposes himself to be within half an hour's walk of them. Italian painters, true to the characteristics of their country, have made their most distant mountains well defined at their summits, and all other objects proportionately distinct; and we are apt to think they have deviated from nature, because the scenery of our own country is never clothed with such fascinating splendour.

The eye can only see a very small part of an object distinctly at once; for the lateral parts of an object are not represented distinctly in the eye; and therefore the eye is obliged to turn itself successively to the several parts of the object it wants to view, that they may fall on or near the axis of the eye, where alone distinct vision is performed.

When the eye is placed above a horizontal plane, the different parts of this plane will appear elevated in proportion to their distance, till at length they will appear on a level with it. For in proportion as the different parts are more distant, the

rays which proceed from them, form angles with the optical axis, IK, fig. 4, pl. IV, more and more acute, and at length become almost parallel. This is the reason why, if we stand on the sea-shore, those parts of the ocean which are at a great distance appear elevated; for the globular form of the earth is not perceptible to the eye; and if it was, the apparent elevation of the sea is far greater than the arch which a segment of the globe would form, within any distance that our eyes are capable of reaching.

The best eye can hardly distinguish any object that subtends at the eye an angle less than half a minute of a degree; and very few can distinguish it when it subtends a minute. If the distance of two stars be not greater than this, they will appear as one.

Though men see distinctly at different distances, by the alterations of the position and figure of the crystalline lens, yet they can only see distinctly beyond a certain extent. This extent is not the same in different people, but in general it is between six and ten inches. A good eye can see distinctly when the rays fall parallel upon it; and then the principal focus is at the bottom of the eye.

The following is a summary of the laws of vision, with regard to the figure of visible objects: 1. If the centre of the eye be exactly in the direction of a right line, the line will appear only as a point. 2. If the eye be placed in the direction of a surface, it will appear only as a line. 3. If a body be opposed directly towards the eye, so that only one plane of the surface can radiate on it, the body will appear as a surface. 4. A remote arch, viewed by an eye in the same plane with it, will appear as a right line. 5. A sphere, viewed at a distance, appears a circle. 6. Angular figures, at a distance, appear round. 7. If the eye look obliquely on the centre of a regular figure, or a circle, the true figure will not be seen, but the circle will appear an ellipse, &c.

Of Optical Instruments and Machines.

Of Spectacles.

By the observations illustrating fig. 4, pl. IV, we hope it is clearly understood, that the nearer any object can be brought to the eye, the larger will be the angle under which it appears, and the more it will be magnified. But objects, we find by experience, may be brought so near the eye, that the advantage of their forming a large visual angle, is more than counterbalanced by the indistinctness that ensues. The generality of people see small objects best, at the distance of eight inches; when such objects are brought nearer than eight inches, they become indistinct, and if to four, or three, they will scarcely be seen at all. The reason of this indistinctness is, that the pencils of rays from objects brought within the limits where distinct vision commences to the naked eye, are in so divergent a state, that they are not converged to points exactly upon the retina. But we have already seen, that a convex glass will lessen the divergence of the most divergent rays passing through it, and that if its curvature be sufficient, it will refract them parallel or even convergent. If, then, an object be viewed at the distance of two or three inches, with a glass of suitable convexity interposed, it immediately becomes distinctly visible at that distance, with the advantage of appearing larger and more enlightened than it would under any circumstances appear to the naked eye. By an obvious parity of reasoning it is evident, that if an object can be rendered distinctly visible by a convex glass, at a less distance than that at which common vision is effected, a person who does not see objects but at an unusual and inconvenient distance, may be made to see them at the common and most eligible distance. Hence the use of convex glasses, which are an invaluable remedy for the visual defect of the long-sighted. Concave glasses, on the contrary, which are directly opposite in their effects to the convex, prove a remedy of equal value to the short-sighted, or those who cannot see distant objects distinctly, and are obliged to bring near objects almost close to their eyes.

By fig. 3, pl. IV, is represented an eye in its perfect state, the image of the object being exactly upon the retina, or as nearly so as could be shewn by an engraving; for we need not inform the most ignorant reader, that of the picture formed by light, no part projects, in the manner shewn by the plate. Fig. 1, pl. V, is the eye of a long-sighted person, where, from the flatness of the crystalline humour, and of the cornea, the

foci of the pencils of rays from objects are not at *d*, where they ought to be, in order to render vision distinct, but tend to a point at F beyond the eye. Hence the rays which flow from the object C, and pass through the humours of the eye, instead of forming an image of a point, from a large speck of light, and when the rays from all parts of an object do the same, the whole image is confused. But if a convex glass, AB, of a proper focus, be interposed, the rays converge sooner, they meet in a point at *d*, on the retina, and distinct vision is obtained.

In fig. 2, from the great convexity of the cornea and crystalline humour, the rays that enter from the object C, converge to a focus in the vitreous humour, as at F, and by diverging from thence, fall as in the example of the long-sighted, obtusely on the retina, and vision is as indistinct as if the eye had been too flat. But by placing a concave glass AB, before the eye, the rays are spread out a little, or fall with greater divergency upon the eye than before, and they do not unite till they fall on the retina, consequently the defect disappears.

When glasses are put in frames for spectacles, their frames ought not to be straight, but bent a little in the middle, so that the axes of both glasses may be directed to one point, at the distance most proper for reading or examining objects in general. By this means the axes of the eyes will fall perpendicularly upon the glasses, and vision will be more distinct.

Spectacles are much better for the eyes than those glasses which are held in the hand. By hand-glasses, indeed, more harm than benefit may eventually result, for the distance at which they are held from the eye is perpetually varied, and the eye is thus perpetually strained, that it may accommodate itself to such changes.

When the eyes of persons first begin to be affected by age, the opticians furnish them with spectacles, the glasses of which are about 40 inches focus, which are therefore called No. 1, or glasses of the first sight. When the focal length is about 16 inches, the lenses are called No. 2. About 12 inches is the focal length of No. 3. Ten inches is what they call No. 4. Nine inches is that of No. 5. Eight inches is the focal length of No. 6. Seven inches is the focal length of No. 7. Six inches is the focal length of No. 8, and sometimes they make spectacles of a focus shorter still. Concave spectacles are distinguished by numbers in the same way. But there is a considerable difference in the focal distances of glasses made by different opticians, though they give them the same number. In chusing spectacles, therefore, actual trial alone can be depended on; and when an actual trial is made, perhaps the best direc-

tion that can be given to make a proper choice, is to prefer those spectacles which, when near the eye, shew objects nearest their natural state, neither enlarged nor diminished, and that give a blackness and distinctness to the letters of a book, without straining the eye, or causing any extraordinary exertion of the pupil. No spectacles can be relied on as properly accommodated to the eyes, which do not procure them ease and rest; if they fatigue the eyes, we may safely conclude, either that we have no occasion for them, or that they are ill-made, or not proportioned to our sight.

In the choice of glasses for the short-sighted, no rules can be laid down; it is a state of the eye which has no connection with age; no stated progression that can be a guide to the optician, in order that he may recommend one glass in preference to another; but the short-sighted themselves, by trying different glasses, will soon discover which are most advantageous.

We shall probably not be charged with taking up too irrelevant a subject, if we introduce a few observations on the means which may be employed to render spectacles unnecessary, or at least to lengthen the period of visual enjoyment without them. The long-sighted should accustom themselves to read and examine objects at a less distance than is entirely agreeable to them; while the short-sighted should attentively pursue a contrary practice. Nothing is more conducive to the preservation of the sight, than the constant use, both in reading and writing, of a moderate degree of light. If in the apartment we commonly use, there are two windows, it is better to sit at an equal distance from both, than to let the principal light come from one side only. In all cases, it should be our object to afford each eye an equal quantity of light.

To flaming colours and white objects, the eyes should not be often or long exposed. The "poor, untutored Indian," when he traverses his native wilderness, while it is every-where covered with snow, fixes before his eyes a wooden frame, which only permits the rays of light to pass through a very minute aperture. His view is thus confined, and his light is small, but he preserves his sight from certain injury. Long or frequent excursions over snow, especially when the sun shines, it will easily perhaps be admitted, must have an injurious tendency to the eyes; but it may be asserted in return, that none of the circumstances attending common life in this country, can occasion an effect so much to be deprecated. The following relation will evince the fallacy of this supposition. A student at Cambridge, who sat daily for several hours in an apartment,

the walls of which were white-washed, felt himself in a short time affected with dimness of sight. A fellow student had the like occasion for complaint. Suspecting the strong light reflected from the walls to be the cause, they had their apartments coloured green; and their eyes then gradually regained their former strength.

After the long interval from exertion occasioned by a night's rest, the sudden exposure of the eyes to a strong light, or the intense exertion of them, has an unfavourable effect. Scarlet window and bed-curtains are, for this reason, the worst that can be chosen. The cataract, a complaint which frequently follows an inflammation of the eyes, and is often irremediable, may be occasioned by looking very frequently at a fire, or any very glaring object.

Green is of all colours the most agreeable to the eyes, and scarlet the most offensive, or endurable for the shortest space of time. White is the next to scarlet. Hats and other coverings for the head, the undersides of which are white, certainly tend to impair the sight.

The affusion of the eyes in clean, soft, cold water, contributes greatly to strengthen them, and of all applications is the most strongly to be recommended. But with respect to the most proper time of performing it, an erroneous opinion is prevalent. Morning is commonly thought to be the most proper time. The middle of the day is certainly to be preferred. Morning is an ineligible time, because the eyes are then well refreshed, and amply replenished with the moisture which is most suitable for them; but when the affusion is postponed till mid-day, it becomes seasonable and beneficial.

Of Burning Lenses and Mirrors.

A burning lens must be convex, a burning mirror must be concave; because both produce their effect by concentrating, into a very small compass, the rays of light and heat, incident upon a large surface.

As the rays which pass through a convex lens, or are reflected from a concave mirror, are united at its focus, their effect is so much the greater, as the surface of the lens or mirror exceeds that of the focus. Thus, if a lens four inches broad collect the sun's rays into a focus at the distance of one foot, the image will not be more than one-tenth of an inch broad. The surface of this little circle is 1600 times less than the surface of the lens, and consequently the density of the sun's rays within it is proportionately increased. It is not

therefore surprising, that large lenses and mirrors burn with irresistible intensity.

The most remarkable burning lens which has ever been constructed, was made by Parker, of Fleet-street, London, at an expense of upwards of £700. It was undertaken with a view to fuse and vitrify such substances as resist the fires of ordinary furnaces, and more especially of applying heat in vacuo, and in other circumstances in which it cannot be applied by any other means. After directing his attention to this object for several years, and performing a great variety of experiments in the prosecution of it, he at last succeeded. His lens was of flint-glass, three feet in diameter, and when fixed in its frame, exposed a surface of two feet eight inches and a half in diameter, without any other material imperfection besides a disfigurement of one of the edges, occasioned by a piece of scoria, which had found its way into its substance. Its weight was 212 pounds; its focal length six feet eight inches; and the diameter of the focus, one inch. To concentrate the rays still further, a second lens was used, and reduced the diameter of the focus to half an inch. Some of the principal effects of this lens are the following:

1. Every kind of wood took fire in an instant, whether hard or green, or soaked in water.

2. Thin iron plates grew hot in a moment, and then melted.

3. Tiles, slates, and all kinds of earth, were almost instantly converted into glass.

4. Sulphur, pitch, and all resinous bodies, melted under water.

5. Fir-wood, exposed to the focus under water, did not seem changed, but when broken, the inside was burnt to a coal.

6. If a cavity were made in a piece of charcoal, and the substances to be acted upon were put in it, the effect of the lens was much increased.

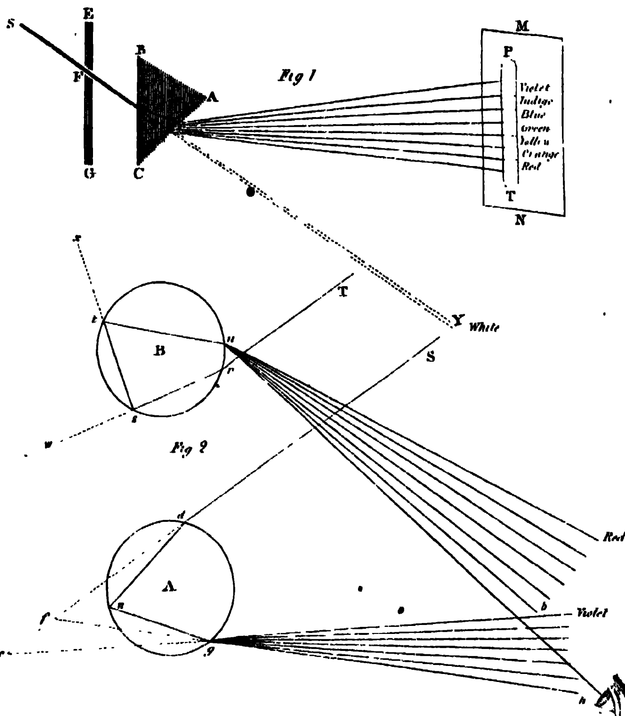
7. Any metal whatever, thus inclosed in the charcoal, melted in a moment, the fire sparkling like that of a forge.

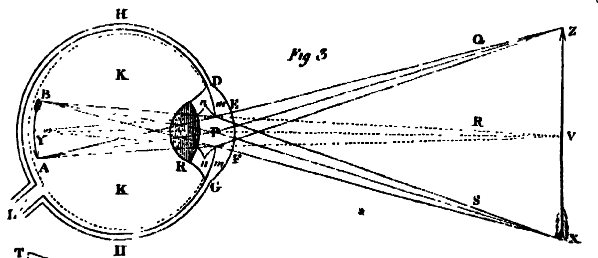
8. The ashes of wood, paper, linen, and all vegetable substances, were instantly turned into a transparent glass.

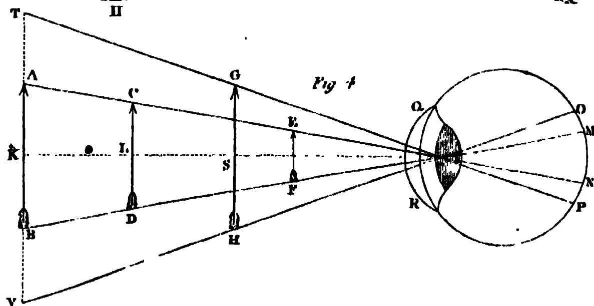
9. The substances most difficult to be wrought upon, were those of a white colour.

10. All metals vitrified on a China plate, when it was so thick as not to melt, and the heat was gradually communicated.

11. When copper was thus melted, and thrown quickly into cold water, it produced so violent a shock as to break the strongest earthen vessels, and the copper was entirely dissipated


Fig 1
Violet
Indigo
Blue
Green
Yellow
Orange
Red
White
Fig 2
Red
Violet


Fig 3


Fig 4

H Corner del.

Though the heat of the focus was so intense as to melt gold in a few seconds; yet there was so little heat at a short distance from the focus, that the finger might be placed about an inch from it without injury. The proprietor had the curiosity to try what the sensation was at the focus, and having put his finger there for that purpose, he described the sensation, not as resembling that produced by a fire or lighted candle, but like that of a sharp cut with a lancet.

If a piece of wood be placed in a decanter of water, and the focus of a large burning glass be thrown upon it, the wood will be completely charred, though the sides of the decanter through which the rays pass will not be cracked, nor any way affected, nor the water perceptibly warmed. If the wood be taken out, and the rays be thrown on the water, neither the vessel or its contents will be in the least affected; but if a piece of metal be put into the water, it soon becomes too hot to be touched, and the water will presently boil. Though pure water alone, contained in a transparent vessel, cannot be heated, yet if by a little ink it be made of a dark colour, or the vessel itself be blackened, the effect speedily takes place.

As all transparent substances, denser than air, when they are spherically convex, or approaching to that form, will converge the rays of light, they may, under particular circumstances, produce effects which few would suspect. A very globular decanter full of water, standing in an apartment where it is exposed to the fervid action of a summer's noontide sun, will converge the incident light with sufficient regularity and intensity to inflame any very combustible body that may happen to be at the proper distance. We have the recollection of a serious fire having arisen from such a cause.

Upon the same principle, we may explain another appearance sometimes observable. If in summer, after much dry weather, a shower of rain falls, and the sun quickly after shines with full splendour, an accurate observer will detect a very curious phenomenon. Many of the leaves and flowers of plants which were entire before the shower, are found to be perforated with small holes. It might be supposed that the caterpillar has renewed his depredations with new vigour, but it is found upon closer examination, that the leaves he never touches are no more exempt from these perforations than others. Perhaps the following considerations will point out to us the truth. If water be thrown upon a dusty floor, it is well known, that it collects itself into small drops or globules. If then heavy drops of rain be thus collected on the dusty leaves, they will in effect be little burning-lenses, and when steadily exposed to the direct rays of a hot sun, they may produce the perforations in question.

Burning mirrors were made in very remote times; the most famous were those of Archimedes and Proclus; by the former of which the Roman ships, besieging Syracuse, according to the testimony of several writers, and by the latter, the navy of Vitalian, besieging Byzantium, were reduced to ashes. Among the moderns, the burning mirror contrived by Buffon is the most remarkable. It is a polyhedron, six feet broad, and as many high, consisting of 160 small mirrors, or flat pieces of looking-glass, each six inches square; by means of this compound mirror, with the faint rays of the sun in the month of March, he set on fire boards of beech-wood at the distance of 150 feet. It may be used to burn downwards, or horizontally, at pleasure; for each of the pieces that compose it is moveable by three screws, so that it may be set to a proper inclination for directing the rays towards any given point; and it turns either in its greater focus, or in any nearer interval. Buffon, at another time, burnt wood at the distance of above 200 feet, and melted silver at 50.

A metallic mirror, of the same size as one of glass, is much superior to the latter in its power of burning: and those metals answer perfectly well which reflect images but indifferently; a piece of tin-plate hammered into the form of a parabola, and well polished, makes an excellent burning mirror.

Of the Camera Obscura.

If a hole be made in a window-shutter or side of a darkened room, the inverted images of all external objects, from which rays of light can enter at the hole, may be observed upon the opposite wall of the room. This is the camera obscura in its most imperfect state. Whether the hole be small or large, the rays are so much scattered, and partly too inflected by the sides of the aperture, that the picture is indistinct, and little interesting. But if a convex glass be applied to the hole, the pencils of divergent rays proceeding from the illuminated objects without, are converged to their proper foci, and if a screen be placed there to receive them, a picture is formed by them, incomparably superior to the happiest efforts of the painter's skill. A large lens, with a considerable focal distance, forms the best image, which is also the most beautiful, when the external objects are all nearly at the same distance. When they are very unequally distant, some confusion arises, because the foci of the pencils of rays proceeding from them require the glass to be at different distances from the screen, and no arrangement can be made to admit of this adjustment. The eye is a natural camera obscura, and we find that we cannot see a near and a distant object distinctly at the same moment; if we

look at the near one, the crystalline lens adjusts itself so that the rays from it are duly converged upon the retina; if we look at the further, another adjustment ensues, or the rays, from their less divergence, would not form a distinct picture on the retina. Hence, as we cannot hope to exceed the works of nature, we must be satisfied with altering the position of the glass or the screen, to suit the objects we most wish to have clear and well defined.

It is necessary, in this experiment of the camera obscura, that the window should not be opposite the sun, otherwise we shall have no image but that of his brightness; and yet it is necessary also, that the sun should illuminate strongly the objects which are to be depicted within, or the rays will be sent so feebly from every part, that the picture will not be brilliant. The inverted position of the image shewn by this camera obscura, is rather an imperfection; but if you take a looking-glass, and hold it before you, with the face towards the picture, and inclining downwards, the image will be seen erect in the glass, and appear with greater brilliancy than upon the screen. The colouring of the picture is exquisitely soft and delicate, every part is in due proportion, the light and shade are distributed with the most accurate propriety, and the motions of all objects perfectly expressed. Thus, in faithful miniature,

——"Hills, dales, and woods appear,
Flocks graze the fields, birds wing the silent air,
In darkened rooms, where light can only pass
Through the small surface of a convex glass:
On the white sheet the moving figures rise,
The forest waves, clouds float along the skies."

The camera obscura is frequently made of a portable size, and sometimes so small that it may be carried in the pocket. The construction of them is sometimes a little varied, but they are all essentially the same in principle. The section of the one we shall describe, is shewn by fig. 3. pl. V. It consists of a rectangular box, ABCD, in the front of which slides a tube F. At the extremity of this tube is a double convex lens, EH. A plane mirror, ST, is contained within the box, and set at an angle of 45 degrees. The pencils of rays flowing from external objects through the convex glass, are reflected upwards by this mirror, and meet in points on IK, which is either a piece of oiled paper, or what is still better, a piece of glass, of which the polish has been removed from one side, by rubbing it with sandstone and water. To an eye looking from the top downward upon the glass IK, a distinct picture of external objects in their proper colours will be perceived, and

with a black-lead pencil their outlines may be traced upon the semi-transparent glass, the rough side of which should always be uppermost. The view will be inverted with respect to right and left, but when the outline has been finished, if the glass be taken and turned down upon a piece of damp paper, and subjected to a gentle pressure for a short time, the pencil-marks on the glass will be transferred to the paper, and the right and left side of the drawing will correspond to those of the objects they are meant to represent. The picture formed upon the glass IK, should be freed as much as possible from all extraneous light: it should therefore have a thin board in the position *B*Y, and from Y should be suspended a curtain of black silk, which should extend over the ends. The inner surface of the board YB, and all the internal parts of the instrument, should likewise be blackened.

The tube in which the convex glass EH is fixed, slides in the forepart of the box, in order that the distance of the glass may be adjusted to the distance of outward objects, and the proper distance is soon discovered, because the picture is then the most distinct. This portable camera obscura may be made in the form of a book, which will contain within itself every part of the instrument except the tube.

The mirror of a camera obscura is commonly made of glass, which contributes not a little to render the instrument imperfect, for the first surface of the glass reflects a part of the incident light, and forms an image which the reflection from the silvered side does not wholly efface, because the rays from the two surfaces do not coincide; and though the whole picture appears exquisitely beautiful to the eye, at a little distance, yet it is found, upon trial, that the double reflection defeats the attempt to make a correct copy. The occasional use of the instrument will, however, furnish the young student of perspective with many useful hints. A metallic mirror, of a composition similar to that employed for telescopes, is a remedy for the defect in question, but adds exorbitantly to the expense.

Dr. Wollaston endeavours to prove that the image formed by the camera obscura is much improved by the use of a convexo-concave lens, instead of the double convex one usually employed. The tendency of the improvement is to make the sides of the picture as distinct as the central part of it. For the Doctor's paper, see the Philos. Trans. for 1812, part II; it contains the necessary data for deriving the greatest advantage from his discovery.

The Magic Lantern and Phantasmagoria.

The magic lantern is a machine employed to throw a magnified image of paintings upon glass or any transparent substance, on a white screen in a darkened chamber. It has generally been devoted to the amusement of children, paintings of a ludicrous description being its usual accompaniments; but it may be employed with propriety to illustrate the principles of the sciences, by a selection of suitable diagrams.

A section of this machine is shewn by fig. 4, pl. V, where ABCD is a tin lantern, from the side of which proceeds a square tube, *b n k l m c*, consisting of two parts; the outermost of which *n k l m*, slides over the other, so that the whole tube may readily be lengthened or shortened. In the end of the arm, *n k l m*, is fixed a convex glass *k l;* about *d e* there is a contrivance for admitting and placing an object *d e*, painted in transparent colours, on a plane thin piece of glass. A single or double convex glass, *b h c*, is employed to cast the light from the flame of the candle, *a*, strongly on the picture *d e*, painted on the plane thin glass. From the shortness of its focus, and consequently great convexity, it is usually called the *bull's eye.* If the object *d e*, be placed further from the glass *k l* than its focus, a distinct image of the object will be projected by the glass *k l*, upon the opposite white wall or screen FH, at *f g*, and it will be in an erect posture, provided care be taken to slide the transparent painting invertedly into its receptacle. If the tube *b n k l m c*, be contracted, and thereby the glass, *k l*, brought nearer the object, *d e*, the representation, *f g*, will be projected so much the larger, and so much the more distant from the glass *k l;* the image may also be enlarged by drawing back the lantern to a greater distance from the screen; but as the image is enlarged, the same quantity of light is spread over a greater surface, and consequently diminishes in distinctness.

The apartment in which the exhibition is made, should be completely darkened, and no light should escape from the lantern except what passes through the glass *b h c*. To increase the light, a concave reflector, ST, is frequently used, of such a curvature, that the candle is in its focus, so that the rays proceeding from it fall parallel upon the glass *b h c*. The glass upon which the pictures are made, is generally of sufficient length to contain several sets of figures; so that when the spectators are satisfied with the first set, by sliding the same glass a little further on, another figure is exhibited.

The exhibition called the Phantasmagoria, which has been

so much admired, is performed by means of a magic lantern, generally one of extraordinary dimensions, but in other respects not much varied in its construction. In the common lantern, the figures are painted on the glass, and all the rest of the glass is left transparent, consequently the image on the screen is a circle of light with the figures in the midst of it; but in the Phantasmagoria, the whole of the glass is made opaque, except the space taken up by the figures painted with the transparent colours, hence this difference in the effect is produced, that no light falls upon the screen but what passes through the figures themselves, consequently there is no circle of light, or any thing but the figures upon the screen. To complete the deception which this change may be made to produce, the following, or some equivalent arrangement, must be resorted to. Let the door of a darkened room, in which the exhibition is to be seen, be set wide open, and let its place be supplied with a screen of thin silk, or fine linen, or of paper rendered transparent. From the outside of the room, let the pictures, painted as above described, be thrown upon the screen, of a very minute size. They will immediately be seen within the room, and though remarkably brilliant, they will be supposed to be distant by the spectators, because they see nothing but the light which comes from them. Let the lantern be drawn back to a greater distance from the screen, and as the images are gradually enlarged, the spectators will suppose them to be actually approaching towards them, and pendent in the air. The chief defect in this exhibition, is, that the images decrease in distinctness as they increase in size; but this might be remedied, if a contrivance were added to the machine, so that the mirror should be wholly covered, and the bull's eye covered in part, at the commencement, and gradually uncovered, as more light was required to keep the enlarged figure as bright or somewhat brighter, than when it was small.

Of Microscopes.

The microscope is an instrument for magnifying small objects. This effect is produced by means of convex lenses. When only one convex glass or lens is used, the instrument is called a *single microscope;* but if two or more are employed conjointly, it is called a *double* or *compound microscope.*

The Single Microscope.

The apparent magnitude of objects is measured by the angle under which they are seen by the eye; and those angles are eciprocally as the distances from the eye. If eight inches be

the nearest limit of distinct vision to the naked eye, and by interposing a lens or other body, we can see with equal distinctness at a nearer distance, the object will appear to be as much larger through the lens than to the naked eye, as its distance from the eye is less than the distance of unassisted vision. If the focal distance of a convex lens be one quarter of an inch, then will that be but one thirty-second part of the common limit of vision or eight inches, so that the lineal dimensions of an object examined with it will be magnified 32 times; the surface 1024 times; and the solidity 1,048,576 times; for these two last numbers are the square and cube of 32. For a lens or spherule of any other focus, the magnifying power is easily found by the same rule.

The simplest microscope which can be employed to any useful purpose, is perhaps that which is made with a drop of water, suspended in a very small hole in a thin slip of brass, or any similar material. This may easily be constructed where no other microscope can be obtained, and its performance will afford not a little pleasure. A spherule of water, it must be observed, of the same size as one of glass, will not magnify so much as the latter, because, as its density is not so great, it has a longer focus. A small drop of water placed on the end of a slender piece of brass wire, and held to the eye by candlelight or moonlight, will, without any other apparatus, magnify in a very surprising manner the animalcula contained in it. The reason is, that the rays coming from the interior surface of the first hemisphere, are reflected so as to fall under the same angle on the surface of the hind hemisphere, to which the eye is applied, as if they came from the focus of the spherule; whence they are propagated to the eye in the same manner as if the objects were placed without the spherule in its focus.

These water microscopes have given rise to the use of other fluids, with several varieties of construction. Brewster describes one in the Appendix to his edition of Ferguson's Lectures. Instead of water, he makes use of very pure and viscid turpentine, which he takes up by the point of a piece of wood, and drops successively upon a thin and well-polished glass: different quantities being thus taken up and dropped in a similar manner, form four or more plano-convex lenses of turpentine varnish, which may be made of any focal length, by taking up a greater or less quantity of the fluid. The lower surface of the glass having been first smoked with a candle, the black pigment below the lenses is then to be removed, so that no light may pass by their circumference. The piece of glass is then to be perforated, and surrounded with a toothed wheel,

which can be moved round the hole as a centre by an endless screw. The apparatus is then placed in a circular case, and this case fixed to a horizontal arm by means of a brass pin, which passes through its upper and under surfaces, and through the hole already mentioned, which does not embrace the pin very tightly, in order that the toothed wheel may revolve with facility. On the upper surface of the circular case is an aperture directly above the line described by the centres of the fluid lenses, when moving round the central hole; and in this aperture is inserted a small cap, with a little hole at its top, to which the eye is applied. A moveable stage carries the slider, on which microscopic objects are laid, and is brought nearer or removed from the lenses by a vertical screw. The objects on the slider are illuminated by a plane mirror, which has both a vertical and horizontal motion for this purpose. When the microscope is thus constructed, the object to be viewed is placed upon the slider, and the endless screw is turned till one of the lenses be directly under the aperture; and the slider is thus raised or depressed by the vertical screw, till the object be brought into the focus of the lens. In this manner, by turning the endless screw, and bringing all the lenses, one after another, directly below the aperture, the object may be successively examined with a variety of magnifying powers. These fluid lenses have been employed as the object-glasses of compound microscopes.

Minute glass spherules make very excellent microscopes, for which we are indebted to Dr. Hooke; but the foci of the smallest sort are so short, that it requires considerable attention and patience to employ them well. F. Di Torre, of Naples, in 1765, sent several glass globules to the Royal Society. The largest of them was only two Paris points in diameter, and is said to magnify the diameter of an object 640 times; another was the size of one Paris point, magnifying the diameter 1280 times; and the smallest no more than one-half of a Paris point, or the 144th part of an inch in diameter; and is said to magnify the diameter of an object 2560 times, and consequently the square of that diameter 6,553,600 times. Globules so exceedingly minute as these, were at one time highly prized, but spherule microscopes are not now made so small, to avoid straining the eyes. The third or smallest globule above mentioned, could only be the 576th part of an inch distant from the object, because the focus of a glass globe is at the distance of one-fourth of its diameter; it is obvious therefore that it would admit very little light, and could not be used without pain and difficulty even by practised observers.

Of the various methods which have been recommended for making glass spherules, the following by Nicholson is perhaps the best. It is observed, by this valuable practical writer, that the usual method has been to draw out a fine thread of the soft white glass called crystal, and to convert the extremity of this into a spherule by melting it at the flame of a candle. But this glass contains lead, which is disposed to become opaque by partial reduction, unless the management be very carefully attended to. He found that the hard glass used for windows seldom fails to afford excellent spherules. This glass is of a clear bright green when seen edgeways. A thin piece, less than one-tenth of an inch broad, was cut from the edge of a pane of glass. This was held perpendicularly by the upper end, and the flame of a candle was directed upon it by the blow-pipe, at the distance of about an inch from the lower end. The glass became soft, and the lower piece descended by its own weight to the distance of about two feet, where it remained suspended, by a thin thread of glass, about $\frac{1}{500}$th of an inch in diameter. A part of this thread was applied endways to the lower blue flame of the candle, without the use of the blow-pipe. The extremity immediately became white, and formed a globule. The glass was then gradually and regularly thrust towards the flame, but never into it, until the globule was sufficiently large. A number of these were made, and being afterwards examined by viewing their focal images with a deep magnifier, proved very bright, round, and perfect.

Spherules are mounted for use, by placing them between two very thin plates of brass or silver, each containing a small hole rather less than themselves. If any imperfection in the globule is discoverable, it is placed on one side, so that it may be covered by the plates. The objects may be placed on the point of a needle, the direction of which should be at right angles to the axis of the eye, to prevent accidents.

In using these spherule microscopes, the objects are to be placed in one focus, and the eye in the other; and from the shortness of the focus, it becomes nearly impossible to view any but pellucid objects, because the nearness of the eye obscures the light.

At page 273, we have adverted to the discoveries of Lewenhoeck; these were all made with single microscopes, which, though spherules in appearance, were in reality double convex lenses. He bequeathed to the Royal Society a cabinet of microscopes made with his own hands. The focus of the greatest magnifier was at the distance of $\frac{1}{20}$ of an inch from its centre, consequently it magnifies the diameter of an object 160 times, the superficies 25,600, and the solidity 4,096,000, on the sup-

position that distinct vision is not naturally effected nearer than eight inches, which is an average distance.

In all microscopes, it is desirable to have the means of viewing objects with ease and steadiness. The following form of a single microscope is very convenient. AB, fig. 5, plate V. is a tablet of wood, ivory, &c. to which is fitted a small handle of the same material. Upon the top of it is fixed a small cylindrical stem, G, and this stem receives the frame containing a lens C, at the focal distance of which a small pair of pliers holding the object, may be placed by means of a slide and adjusting screw L. The pliers are opened by means of two little studs, *a e*. The eye is at the other focus of the lens, and the object is of course seen magnified according to the power of the lens employed. This instrument, enclosed in a case, may be carried in the pocket without encumbrance. Lenses, the focal lengths of which are from three to five-tenths of an inch, are the most suitable for ordinary use.

Dr. Wollaston has proposed an improvement of microscopes, which he thinks highly advantageous. The great desideratum, he observes, in employing high magnifiers, is sufficiency of light; and it is accordingly expedient to make the aperture of the little lens as large as is consistent with distinct vision. But if the object to be viewed is of such magnitude as to appear under an angle of several degrees on each side of the centre, the requisite distinctness cannot be given to the whole surface by a common lens, in consequence of the confusion occasioned by the oblique incidence of the lateral rays, excepting by means of a very small aperture, and proportionable diminution of light. In order to remedy this inconvenience, he used two plano-convex lenses ground to the same radius, and applied their plane surfaces on opposite sides of the same aperture in a thin piece of metal. Thus he virtually obtained a double convex lens, with this advantage, that the passage of oblique rays was at right angles with the surfaces, as well as the central pencil. With a lens so constructed, the perforation that appeared to give the most perfect distinctness, was about one-fifth part of the focal length in diameter, and when such an aperture is well centred, the visible field is at least as much as twenty degrees in diameter. It is true, that a portion of light is lost by doubling the number of surfaces, but this is more than compensated by the greater aperture which, under these circumstances, is compatible with distinct vision.

Ellis's single aquatic Microscope.

This instrument takes its name from John Ellis, the author of an essay towards a natural history of corallines, and of many curious and uncommon zoophytes. It enabled him to pursue his investigations, relative to the structure and economy of these wonderful productions of Nature, with considerable success; and it is well adapted to shew botanical subjects. It is simple in its construction, very portable, and commodious in use. It is represented by fig. 6, pl. V.

The whole apparatus is contained in a small box or case, K, which is generally covered with fish-skin. On the top of the box there is a socket, for receiving the screw which is at the bottom of the brass pillar, A, when the instrument is prepared for use. D is a cylindrical brass pin, which exactly fills and slides up and down in a hole drilled in the middle of the pillar A. The pin D is moveable, in order to adjust the lenses to their focal or proper distances from the object. It may be fastened at any height by the screw Z, which presses against it; at the top of it is a socket, to receive the arm or bar E, which carries the magnifiers. The arm E may be moved backwards and forwards in the socket X, and sideways by turning it with the pin D; so that the magnifier, which is screwed into the ring at the end of the bar E, may be easily made to traverse over any part of the object lying on the stage or plate B.

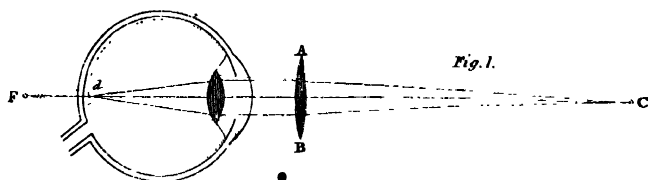
F is a polished silver speculum, with a magnifying lens placed at the centre of it, which is perforated for the purpose. The silver speculum screws into the arm E, as at F. G, another speculum, with its lens, which is of a different magnifying power to the former. H is a brass semi-circle, which supports the mirror I; the pin R of this semi-circle passes through a hole towards the bottom of the pillar A. B, the stage on which the objects are to be placed; it fits into a small dove-tailed arm, which is at the upper end of the pillar A. C, a plane round glass, with a small piece of black silk stuck on it, is used to lie in a circular groove made in the stage B. A hollow-glass, like a watch-glass, is occasionally laid on the stage instead of the plane glass. L, a pair of nippers. These are fixed to the stage by the pin at the bottom; the steel wire of these nippers slides backward and forward in the socket, and this socket is moveable upwards and downwards by means of the joint, so that the position of the object may be varied at pleasure. The object may be fixed in the nippers, stuck on the point, or affixed by a little gum-water, &c. to the ivory

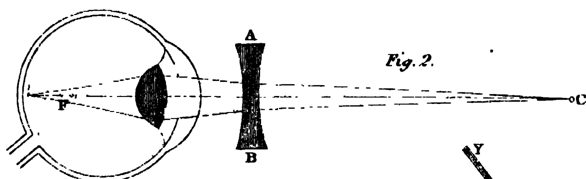
cylinder N, which screws, when occasion requires, to the point of the nippers.

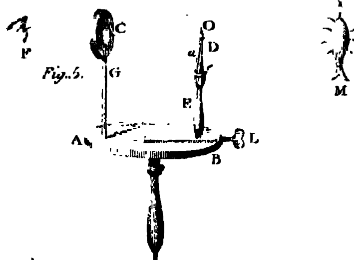
To use this microscope, after taking all the parts of the apparatus out of the box, begin by screwing the pillar A to the cover; pass the pin R, of the semi-circle which carries the mirror, through the hole which is near the bottom of the pillar A; push the stage into the dove-tail at B, slide the pin D into the pillar; then pass the bar E through the socket X, which is at the top of the pin D, and screw one of the magnifying lenses into the ring at F. These operations, which are performed in a very short time, in a less time, indeed, than is necessary to describe them, prepare the microscope for use. Let the object be now placed either upon one of the glasses of the stage, or in the nippers L, and in such a manner that it may be as nearly as possible over the centre of the stage. Bring the speculum F over the part you mean to observe; then throw as much light as possible on the speculum, by means of the mirror I, which, it will be perceived, admits of a double motion—one horizontally, the other to set it in any required angle: the light received by the speculum is reflected by it on the object. The distance of the lens F from the object, is regulated by moving the pin D up and down, until a distinct view of it is obtained. The best rule is, to place the lens beyond its focal distance from the object, and then gradually to slide it down till the object appears clear and well defined. The adjustment of the lenses to their foci, and the distribution of the light on the object, are what require the most attention; but the management of the instrument is easily acquired by a little practice. This microscope is sometimes furnished with a rack and pinion, for more steadily elevating or depressing the pin D, in adjusting the lens to its focus. The mirror I should be tried in positions variously inclined to the object, in order to ascertain that in which it reflects the light best adapted to observation.

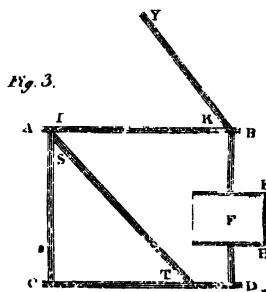
The Hand Megalscope.

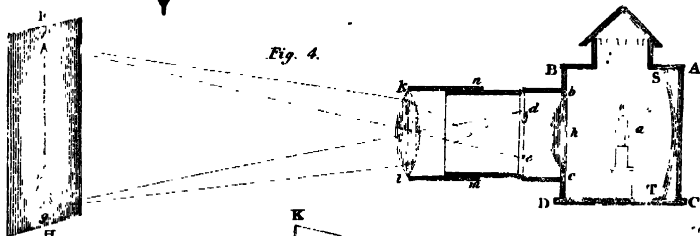
This instrument was contrived by Martin, and is well adapted for viewing the larger sort of small objects expeditiously. A, fig. 7, plate V, is the case of brass, tortoise shell, &c. with its three lenses D, E, F, each surrounded by a rim or frame of the same material as the case. H is the handle. The lenses are commonly of 1, 1½, and 2 inches focus; as they all move on the same pin, they turn over each other, and can be used either conjointly or separately. The three lenses singly, afford, of course, three magnifying powers, and by combining two and two, we obtain three more: for D with E makes one, D with F another, and E with F a third; and all three together make

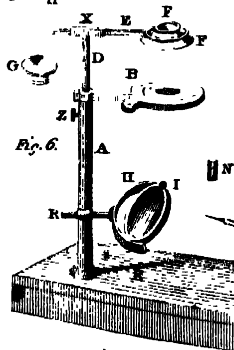

Fig. 1.
A
B
C
F
d

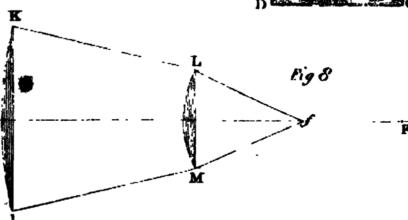

Fig. 2.
A
B
C
F

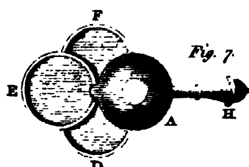

Fig. 5.
C
G
O
D
E
A
B
L
M


Fig. 3.
Y
A
I
K
B
S
E
F
H
T
C
D


Fig. 4.
H
B
A
S
k
n
b
d
h
a
c
l
m
T
D
C


Fig. 6.
X
E
F
F
G
D
B
Z
A
H
I
N
K
L


Fig 8
K
L
f
F
M
I


Fig. 7.
F
E
A
H
D

another; so that by this simple apparatus we have seen different magnifying powers. When the three lenses are combined, it is better to turn them in, and look through them by the small aperture in the sides of the case, the eye will not then be incommoded by external light; the distortion of objects by the sides of the glasses will be prevented, and the eye will coincide more exactly with the common axes of the lenses.

Double or Compound Microscope.

Compound microscopes present to the eye, not the object itself, like the single microscope, but its image.

In treating of these instruments and of telescopes, the lens which is next to the object is called the object-glass, and all the other lenses are called eye-glasses.

Fig. 1, pl. VI. represents the two lenses of a compound microscope; *a b c* is a small object, placed at a little greater distance from the object glass *d e f*, than its principal focus: pencils of rays proceeding from the object, pass through the glass, by which they are converged,' and united in points at ABC, where an image is formed, which is larger than the object, in proportion as the distance B *e* exceeds the distance *e c*. The eye-glass, DEF, is so placed, that its focus is at B, and the eye, to view the image, must be about the same distance on the other side. The rays of each pencil will be parallel after going out of the eye-glass, but they will be again converged by the refractive powers of the eye, and will form on the retina, a large inverted image of the object; for it is evident that it is seen, by the interposition of the glasses, under the angle IFD, instead of the angle which to the naked eye would be contained between *b* I *a*.

The magnifying power of this microscope is easily computed. In the first place, the image AC is to the object, as the distance B *e* is to the distance *e c*; and secondly, the image AC will be seen by the eye at I, under the angle DIF, which is equal to the angle AEC; and therefore the image will appear as much longer than to the naked eye, as the distance BE is shorter than eight inches, (or the limit of distinct vision to the naked eye;) so that, if the distance *e c* be one inch, *e*B six inches and EB two inches, then the image AC is six times longer than the object *a b*, and that image is magnified four times by the lens DF. Hence if four be multiplied by six, we shall have the total power of the microscope, which magnifies the diameter of objects 24 times, their superficies 24 times 24, or 576 times, and their solidity 13,824 times.

This microscope has a larger field of view than a simple microscope of the same power, and its field of view may be further enlarged by the addition of one or two more lenses instead of the single lens DF. The magnifying power of the instrument with more than two lenses, must be computed from the effect of all the lenses; or it may be ascertained experimentally in the following manner: Place part of a divided ruler before the microscope, so that, looking through the instrument, you may see one of its divisions magnified; then open the other eye also, and, looking with it at the ruler out of the microscope, the image of the magnified division will seem to be projected on the ruler; and you may easily see how many divisions, of the unmagnified ruler, measure or are equal to the single magnified division, and that number is the magnifying power of the microscope. Thus, if the ruler be divided after the common way, into inches and tenths, and one-tenth is magnified, so as to appear equal to three inches, you may conclude that the microscope magnifies the diameter or length of objects thirty times.

The Solar Microscope.

This microscope is sometimes called the camera obscura microscope, but it still more nearly resembles the magic lantern in its effect. The exhibition it affords is made in a darkened room, and it can only be used when the sun shines.

This instrument consists of one plane mirror, and two lenses; the mirror, *s o*, fig. 2, pl. VI. must be without the window shutter *d u*; the lens *a b* in the shutter; and the lens *n* within the dark room. The lens *a b* is inclosed in a brass tube, and the lens *n* in another smaller tube, which slides in the former, for the purpose of adjusting it to the proper distance from the object. The mirror can be so turned by adjusting screws, that however obliquely the incident rays EF fall upon it, they can be reflected horizontally into the dark room, through the illuminating lens *a b*. This lens collects those rays into a focus near the object *c g*; and passing on through the object, they are met by the magnifier *n*: here the rays cross, and proceed divergently to a vertical white screen prepared to receive them, on which screen the image or shadow, *q r*, of the object will appear. The magnifying power of this instrument depends on the distance of the white screen; and in general bears a proportion to the distance of the object *c g* from the magnifier *n*; that is, if the screen be ten times that distance from the lens *n*, the image will be ten times as long, and ten times as broad, as the object. About ten or twelve feet is the best distance, for,

if further off, the image, though larger, will be obscure, and ill-defined.

A telescope may be converted into a microscope, by removing the object-glass to a greater distance from the eye-glass. And since the distance of the image is various, according to the distance of the object from the focus, (and it is magnified the more, as its distance from the object is greater,) the same telescope may be successively converted into microscopes, which magnify in different degrees.

Opaque Microscope.

The solar microscope above described, is calculated only to exhibit transparent objects, or at least such as permit a part of the incident light to pass through them; to view opaque objects, another mirror must be used, in order that they may be seen by the light they reflect. In fig. 3, pl. VI, the mirror *a*, and the lens *c*, are the same as in the common solar microscope; but the converging rays from *c* are met by a mirror *e n*, placed diagonally, and which throws up the rays much condensed upon the opaque object SR; from the object they are reflected to the magnifier O, from which they proceed diverging to the screen *p q*, where the object will be painted and greatly magnified. The objects are generally stuck by a wafer, or gum-water, to a thin slider of wood, and not placed in the focus of the lens C, to prevent their being burnt. The feathers of birds, seeds of plants, sections of wood, together with sponges, ferns, and similar objects, exhibit very interesting appearances in this microscope.

Of Microscopic Objects.

Whatever object offers itself as the subject of our examination with the microscope, the size, contexture, and nature of it, are first to be considered, in order to examine it with such glasses, and in such a manner, as may shew it best. The first step should always be to view the whole of it together, with a magnifier that will take the whole of it in at once; and after this, the several parts of it may the more fitly be examined, whether remaining on the object or separated from it. The smaller the parts are, the more powerful ought the magnifiers to be which are employed. The transparency or opacity of the object must also be considered, and the glasses employed must be selected accordingly; for a transparent object will bear a much greater magnifier than one which is opaque, since the nearness of the eye, when a high magnifier is used, unavoidably darkens an object, in its own nature opaque, and renders it very difficult to be seen, unless by the help of an apparatus

contrived for that purpose, like Ellis's microscope, with a silver speculum. Most objects, however, become transparent by being divided into extremely thin parts.

The nature of the object also, whether it be alive or dead, a solid or a fluid, an animal, a vegetable, or a mineral substance, must likewise be considered, and all the circumstances of it attended to, that we may proceed in the most advantageous manner. If it be a living object, care must be taken not to squeeze or injure it, that we may see it in its natural state and full perfection. If it be a fluid, and that too thick, it must be diluted with water; and if too thin, we should let some of its watery parts evaporate. Some substances are fittest for observation when dry, others when moistened, and others after they have been kept for some time.

Light is the next thing to be taken care of, for on this the truth of all our observations depends; a little experience will shew how very differently objects appear in one degree of it to what they do in another. Hence, every new object should be viewed in all degrees of light, from the greatest glare of brightness to perfect obscurity; and in all positions to each degree, till we obtain all the evidence we can of its form and figure. In many objects it is very difficult to distinguish between a prominency and a depression, a black shadow and a black stain; and in colour, between a bright reflection and whiteness. The eye of a fly in one kind of light appears like a lattice drilled full of holes, in the sun-shine like a solid substance covered with golden nails; in one position like a surface covered with pyramids; in another with cones, and in others with still different shapes.

The degree of light must always be suited to the object. If that be dark, it must be seen in a full and strong light; but if transparent, the light should be proportionably weak; for which reason, there is a contrivance, both in the single and double microscope, to cut off the superabundant rays, when such transparent objects are to be examined with the largest magnifiers. Light admitted into a darkened room, through a hole in a window-shutter, suits microscopic observations extremely well. The light of a candle, is, for many objects, and especially for such as are very bright, transparent, and minute, preferable to day-light; for others, a serene day-light is best: but sun-shine is the worst light of all. This remark does not apply to the solar microscope, for which nothing but sun-shine will answer, and the brighter it is, the better; with this instrument, however, we do not see the object itself on which the sun-shine is cast, but only the image or shadow of it greatly extended on a screen; and therefore no

confusion can arise from the glaring reflection of the sun's rays from the object to the eye, as with other microscopes. And with the solar microscope, we must rest contented with viewing the true figure of an object, without expecting to find its natural colour; since no shadow can possibly exhibit the colour of the body which it represents.

Most objects require also some management, in order to bring them properly before the glasses. If they are flat and transparent, and such as will not be injured by pressure, the best way is to inclose them between two thin pieces of Muscovy talc, fastened by brass rings in a hole made through a slip of metal or ivory, called a slider. By this means we may very conveniently preserve the feathers of butterflies, the scales of fishes, and the farina of flowers, as also the parts of insects, the whole bodies of minute ones, and a great number of other objects. Each slider should contain three, four, or more holes, which should not be filled promiscuously; but all the objects preserved in one slider should be such as require the same magnifying power to view them, that there may not be a necessity of changing the glasses for every object; and the sliders should be marked with the number of the magnifier to be used in viewing what it contains. In placing the objects in the sliders, it is proper to have at hand a small magnifier, of about an inch focus, to examine and adjust them by, before they are fixed down with the rings.

Small living objects, such as lice, fleas, bugs, mites, minute spiders, &c. may be placed between the talcs without injuring them, if care be taken to lay on the brass rings without pressing them down; but if they are too large to be treated thus, they should be either preserved between two concave glasses, or else viewed immediately, by holding them in the pliers, or sticking them on the point, with which the other end of that instrument is usually furnished.

The circulation of the blood may be most easily seen in the tails and fins of fishes, in the fine membranes between the toes of a frog, or best of all in the tail of a water-newt. Such parts of objects of this description as are intended to be particularly viewed, must be expanded within a glass tube; several sizes of glass tubes usually accompany a microscope, and such a one should be selected as will just admit the object, which will then remain more quiet to be examined.

If fluids come under examination, to discover the animalcula they contain, a small drop is to be taken with a hair pencil, or on the nib of a clean pen, and placed on a plate of glass. If they are too numerous to be thus seen distinctly, some lukewarm water must be added to the drop; they will

then separate, and may be seen extremely well. But if we are to see the salts in a fluid, the contrary method must be observed, and the plate of glass must be held gently over the fire, till part of the liquor is evaporated.

The dissection of minute animals requires considerable patience and care; but may be done very accurately by means of a needle and a fine lancet, placing the subject in a drop of water, for then the parts will readily unfold themselves, and will be very distinctly seen.

Such may be the methods resorted to for preserving transparent objects; but the opaque ones, such as seeds, woods, &c. require a very different treatment, and are best preserved and viewed in the following manner:

Cut card-paper into small slips, about half an inch long, and the tenth of an inch broad; wet these half way of their length in gum-water, and with that fasten on several parcels of the object. These are very convenient for viewing by the microscope made for opaque objects with the silver speculum; but they are proper for any microscope adapted for opaque bodies.

A small box should be contrived for these slips, with little shallow holes for the reception of each: and this is conveniently done, by cutting pieces of pasteboard, such as the covers of books are made of, to the size of the box, so that they will just go into it; and then cutting holes through them with a small chisel, of the shape of the slips of card; these pasteboards having then a paper pasted over their bottom, are cells very proper for the reception of these slips, which may easily be taken out by means of a pair of pliers, and will be always ready for use.

Great caution is necessary, in forming a judgment on what is seen by the microscope, if the objects are extended or contracted by force or dryness. Nothing can be determined respecting them, without making the proper allowances, and different lights and positions will often shew the same object as very different from itself. There is no advantage in any greater magnifier than such as is capable of shewing distinctly the object viewed; and the less the glass magnifies, the more pleasantly the object is seen.

In general, the colours of objects are less to be depended on in proportion as the magnifying power by which they are viewed is greater; for their several component particles being by this means removed to greater distances from one another, may give reflections very different from what they would if seen by the naked eye.

The motions of living creatures, also, or of the fluids con-

tained in their bodies, are by no means to be hastily judged of from what we see by the microscope, without due consideration; for as the moving body, and the space in which it moves, are both magnified, the motion must be so too; and therefore that rapidity with which the blood seems to pass through the vessels of small animals must be judged of accordingly: suppose, for instance, that a horse and a mouse move their limbs exactly at the same time, if the horse runs a mile while the mouse runs fifty yards; though the number of steps are the same in both, the motion of the horse must notwithstanding be allowed to be the swiftest, and the motion of a mite, as viewed by the naked eye, or through the microscope, is perhaps not less different.

Of Telescopes.

Telescopes are instruments employed for discovering and viewing distant objects. They are of two kinds—*refracting* and *reflecting;* the former consist of different lenses, through which the objects are seen by rays refracted by them to the eye; but the latter consist of specula, by which the rays are reflected, with lenses to magnify the image formed by the specula.

The principal effects of telescopes depend upon this maxim, that objects appear larger in proportion to the angles which they subtend at the eye; and the effect is the same, whether the pencils of rays, by which objects are visible to us, come directly from the objects themselves, or from any place nearer to the eye, where they may have been united so as to form an image of the object, because they issue again, in certain directions, from those points where there is nothing to intercept them, in the same manner as they did from the corresponding points in the objects themselves. In fact, therefore, all that is effected by a telescope, is, first to make such an image of a distant object, by means of a lens or mirror; and then to give the eye some assistance for viewing that image as near as possible; so that the angle which it shall subtend at the eye, may be very large, compared with the angle which the object itself would subtend in the same situation. This is accomplished by means of an eye-glass, which so refracts the pencils of rays, that they may afterwards be brought to their several foci by the humours of the eye. But if the eye was so formed as to be able to see the image with sufficient distinctness at the same distance without an eye-glass, it would appear as much magnified as it does when

a glass is used for that purpose, though it would not in all cases have so large a field of view.

Although no image be actually formed by the foci of the pencils without the eye, yet if, by the help of any eye-glass, the pencils of rays shall enter the pupil, just as they would have done from any place without the eye-glass, the visual angle will be the same as if an image had been actually formed in that place.

The forms of refracting and reflecting telescopes have been frequently varied, and sometimes they are distinguished by the name of their inventor, as the Galilean and Newtonian telescopes; sometimes by the particular use for which they are most proper, as the "land telescope," "the night-glass, or astronomical telescope;" and sometimes by one of their remarkable properties, as the "achromatic telescope." We shall in the first place notice refracting telescopes.

The Astronomical Telescope.

This telescope consists of two convex lenses, AB, KM, fig. 4, pl. VI. each fixed at the extremity of a different tube. One of the tubes is very short, as its use is merely to adjust the focus in proportion to the distance of the object viewed; and it slides within the other. The tubes are not represented in the figure, as the external form of telescopes are familiar almost to all. Contrary to the arrangement which takes place in the micro scope, the glass which has the longest focus is presented to the object, and therefore constitutes the object-glass.

PR represents a very distant object, from every point of which rays come so very little diverging to the object lens KM of the telescope, as to be nearly parallel: *p r* is the picture of the object PR, which would be formed upon a screen situated at that place. Beyond that place, the rays of every single radiant point proceed divergently to the eye-glass, AB, of greater convexity, and which causes the rays of each pencil to become parallel, in which direction they enter the eye of the observer at O.

The axes of the two lenses are coincident, in the direction QLO; L *q* is the focal distance of the object-glass, and E *q* is the focal distance of the eye-glass; consequently the distance between the two glasses is equal to the sum of their focal distances. An object viewed through this telescope, by an eye situated at O, will appear magnified and distinct, but inverted. The object seen without the telescope, will be, to its appearance through the telescope, as *q* E to *q* L; that is, as the focal distance of the eye-glass to the focal distance of the object-

glass. For the pencils of rays, which, after their crossing at *r q p* proceed divergently, fall upon the lens AB, in the same manner as if a real object were situated at *r q p*, and consequently, after passing through that lens, the rays of each pencil proceed parallel. Now to the eye at O, the apparent magnitude of the object PR, is measured by the angle BOA, or by its equal *p* E *r*; but to the naked eye at L, when the glass is removed, the apparent magnitude of the object is measured by the angle PLR, or by its equal *r* L *p*; therefore the apparent magnitude to the naked eye, is to the apparent magnitude through the telescope, as the angle *r* L *p* is to the angle *p* E *r*; or as the distance *q* E is to the distance *q* L.

If the angles *r* L *p* and *p* E *r* were equal to each other, the telescope would not magnify, and they would be equal, if the lenses were of equal focal distance. Hence, as the magnifying power of the telescope is produced by making the focal distance of the eye-glass less than that of the object-glass, it will easily be perceived, that the greater the difference of the focal lengths, the greater will be the magnifying power. In practice, however, it is found that they may be so disproportionate, that the increased magnifying power is overbalanced by the indistinctness which ensues. In order, therefore, to obtain a very great magnifying power, with the preservation of just proportion, these telescopes have sometimes been made one hundred feet or upwards in length; and as they were used for astronomical purposes, or mostly in the night time, they were frequently used without a tube; viz. the object lens was fixed on the top of a pole, in a frame capable of being moved by a cord or wire in any required direction, and the eye-glass, fixed in a short tube, was held in the hand, or fitted to another frame about the height of the observer, so as to be susceptible of a simultaneous movement. A telescope of this description was called an *aërial telescope*. Its use is evidently incommodious; but such was the incredible pains taken by philosophers in exploring the wonders which even the imperfect telescopes at first constructed promised to lay open, that with such an instrument the five satellites of Saturn, and many other remarkable objects, were discovered.

The length of common refracting telescopes must be increased in no less a proportion than the square of the increase of their magnifying power; so that in order to magnify twice as much as before, with the same light and distinctness, the telescope must be lengthened four times, and to magnify three times as much, nine times. On this account, their unwieldy length, when great powers are desired, is unavoidable.

The breadth of an object-glass adds nothing to the magnify-

ing power; for whatever it may be, the image will be equally formed at the distance of its focal length; but the brilliancy of the image will be increased by the breadth, as a greater number of rays will then diverge from every point of the image.

The magnifying power, and the field of view, in this telescope, may be increased by using two plano-convex lenses, combined so as as to act like one glass, and such a combination is now generally employed. The disproportion above alluded to, which may subsist between an object-glass and an eye-glass, arises from this circumstance, that a lens does not converge the rays of the same radiant point, exactly to the same refracted focus, and the indistinctness, which is thus occasioned in the image, increases with the thickness of the lens and the increase of its curvature. Hence arises the limitation to the use of highly magnifying eye-glasses. The field of view is enlarged by enlarging the eye-glass: but if a lens of very short focus were made large, the irregularity of its refraction would throw the view into confusion; if it were made sufficiently small to prevent this, it would be equally useless from its contracted field of view, and the want of light. But if two plano-convex lenses be used, the curvature of both conjointly will be less than the curvature of a single lens of equal magnifying power; such a combination therefore will improve the eye-glass of a telescope, because the aberration of the rays passing through it will be less than through a single lens of the same focus. Let IK, fig. 8, plate V, be a plano-convex lens, of which the focus is at F, so that an object placed at F would be seen magnified through it. If another lens LM be placed between the first lens and its focus, the focus of the rays passing through both will be shortened, and will fall at about the distance *f*, so that, when thus combined, they will act like a single lens of much greater curvature.

The Night Glass.

The telescope called a *night-glass* is nothing more than the common astronomical telescope, with tubes, and made of a short length, with a small magnifying power. Its length is usually about two feet, and it is generally made to magnify from six to ten times. It is much used by navigators at night, for the purpose of discovering objects that are not very distant, but which cannot otherwise be seen for want of sufficient light, such as vessels, coasts, rocks, &c. From the smallness of its magnifying power, and the obscurity of the objects upon which it is employed, it admits of large glasses being used, and consequently has an extensive and well-enlightened field of view.

The Terrestrial Telescope, or Perspective Glass.

The astronomical telescope, by the use of two additional eye-glasses, shews objects in their right position, and becomes a terrestrial telescope, that is, adapted for looking at objects on the earth.—It is still more frequently called, a perspective glass. This telescope is shewn by fig. 5, plate VI. The rays of each pencil coming from the image LM of the object IK, emerge parallel from the lens AB, and having crossed at its focus, O, they continue in that direction to the lens EF, in consequence of which they form an image ST at the focus of the second lens, and again diverging, they fall upon the third lens, CD, in the same manner as they did upon the lens AB; therefore, after their emergence from this last lens, they fall parallel upon the eye at G. But as the last image ST, is not inverted as at LM, but in the same position as the object IK, the eye sees a true or upright picture, as if the rays had come directly from the object.

The last lens, or the one nearest to the eye, in this telescope, is mostly now made double, that is, two plano-convex lenses are substituted for the double convex one, for the purpose of enlarging the field of view, as pointed out for the eye-piece of the astronomical telescope. By this means all the best terrestrial telescopes contain four lenses in the tube next the eye.

The Galilean Telescope.

A report having reached the illustrious Galileo, that an optical instrument had been constructed, by means of which distant objects appeared as if they were near; that philosopher, forcibly struck with the advantage which might be derived from the contrivance, instantly directed his attention to the discovery of its nature. The night after he heard the account, the construction of such an instrument occurred to him; the day following he put the several parts of it together, and the telescope which he thus invented is still called by his name. With that noble frankness for which he was remarkable, and which ought always to distinguish the true philosopher from the empiric, he forthwith explained publicly the structure and wonderful uses that might be made of the instrument; and shortly afterwards, as an acknowledgment of his merit, the Republic of Venice more than tripled the salary of his professorship.

Galileo's telescope consists of a convex object-glass, and a concave eye-glass, as represented by fig. 6, pl. VI. The distance between the two lenses is less than the focal distance of the object-glass; but the concave glass is situated so as to

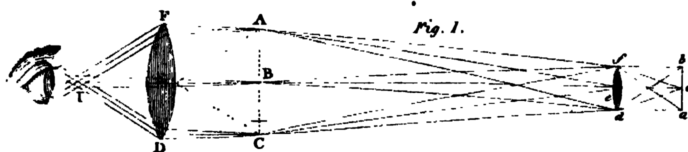
make the rays of each pencil fall parallel upon the eye, as is evident by conceiving the rays to go back again through the eye-glass, towards O; EO being the focal length of the eye-glass.

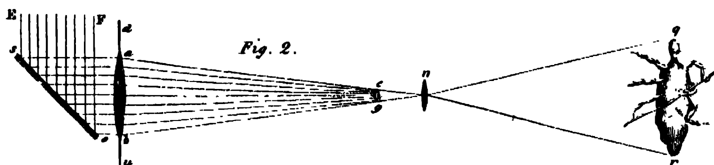
When the sphere of concavity in the eye-glass of a Galilean telescope is equal to the sphere of convexity in the eye-glass of another telescope, their magnifying power is the same; but the concave glass being placed between the object-glass and its focus, the Galilean telescope will be shorter than the other, by twice the focal length of the eye-glass. Hence, if the lengths of the telescopes be the same, the Galilean will have the greatest magnifying power.

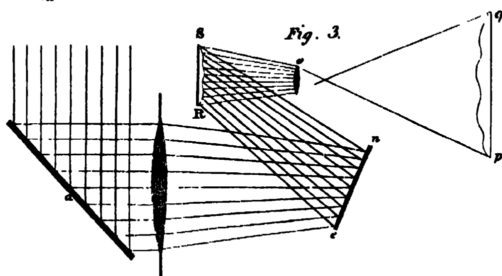
The field of view, or quantity of objects taken in by the Galilean telescope, does not depend, as in those with convex glasses, upon the size of the eye-glass, but upon the breadth of the pupil of the eye; because the lateral pencils of rays diverge from the axis of the eye-glass at their emergence from it. Upon this account, the eye should be placed as near to the eye-glass as possible, in order that it may receive the greatest number of pencils. Yet no nearness of the eye will wholly prevent the field of view from being more confined than with convex eye-glasses of equal curvature; but this disadvantage is counterbalanced by the valuable property of superior distinctness.

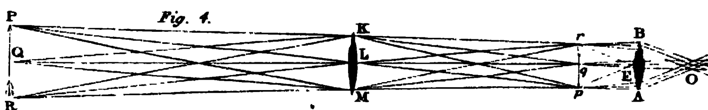
The Achromatic and Aplanatic Object-glasses.

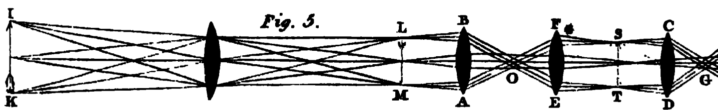
The ordinary telescopes which we have hitherto described, will only bear a small aperture, without exhibiting circular prismatic rings of colours, which are subversive of their utility. Two causes contribute to this effect, 1, Spherical surfaces do not refract the rays of light accurately to a point; and 2, The rays of compounded light, being differently refrangible, come to their respective foci at different distances from the glass, the more refrangible rays converging, of course, sooner than the less refrangible. This may be proved by an easy experiment; for if the image of a paper painted entirely red, and properly illuminated, be cast by means of a lens upon a screen, it will be formed at a greater distance than the image of a blue paper cast by the same lens. Hence the image of a white object is composed of an indefinite number of coloured images, the violet being nearest, and the red furthest from the lens, and the images of intermediate colours at intermediate distances. The whole image is therefore in some degree confused, though its extremities are most perceptibly so; and this confusion being very much increased, not only by the magnifying power of the eye-glass, but also by the dispersive power which it has in common with the object-glass, the necessity for that limitation

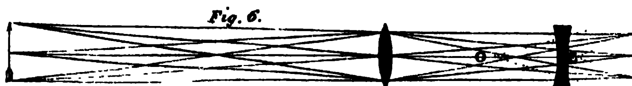












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which has been already intimated, for a certain moderate proportion between the object and eye-glass, becomes indispensable. Under these circumstances, to increase the length of refracting telescopes, seemed to constitute the only means of obtaining great magnifying powers; and though a method of converging to the same point all the rays of light which is composed, still remained an object of speculation, the attainment of it seemed, in the days of Newton, to be attended with insuperable difficulties. But however great they were, they have been nearly overcome, and the signal merit of this success is due to our countryman John Dollond. By making a compound lens of three different substances, of different refrangible powers, the rays of light, which were too much dispersed by one convex lens, are brought nearer to a union with each other; the telescopes made with an object-glass of this kind are now commonly used, and are distinguished by the name of *achromatic* telescopes, a prefix which signifies *colourless.*

The object-glasses of Dollond's telescopes are composed of three distinct lenses, two of which are convex and the other concave. The concave one is, by British Artists, placed in the middle, as represented in fig. 1, pl. VII, where *a* and *c* shew the two convex lenses, and *b b* the concave one. The two convex ones are made of London crown glass, and the middle one of white flint-glass, and they are all ground to spheres of different radii, according to the refractive powers of the different kinds of glass, and the intended focal distance of the object-glass of the telescope. According to Boscovich, the focal distance of the parallel rays for the concave glass is one-half, and for the convex glass one-third of the combined focus. When put together, they refract the rays in the following manner: Let *a b*, *a b*, fig. 2, pl. VII, be two red rays of the sun's light falling parallel on the first convex lens *c*. Supposing there was no other lens present but one, they would then be converged into the lines *b e*, *b e*, and at last meet in the focus *q*. Let the lines *g h*, *g h*, represent two violet rays falling on the surface of the lens. These are also refracted, and will meet in a focus; but as they have a greater degree of refrangibility than the red rays, they must of consequence converge more by the same power of refraction in the glass, and meet sooner in a focus, suppose at *r*.—Let now the concave lens, *d d*, be placed in such a manner as to intercept all the rays before they come to their focus. If this lens was made of the same materials, and ground to the same radius as the convex one, it would have the same power to cause the rays to diverge, that the former had to make them converge. In this

case, the red rays would become parallel, and move on in the lines *o o, o o;* but the concave lens being made of flint-glass, and upon a shorter radius, has a greater refractive power, and therefore they diverge a little after they come out of it; and if no third lens was interposed, they would proceed diverging in the lines *o p t, o p t;* but, by the interposition of the third lens *o v o*, they are again made to converge, and meet in a focus somewhat more distant than the former, as at *x*. By the concave lens, the violet rays are also refracted, and made to diverge; but having a greater degree of refrangibility, the same power of refraction makes them diverge somewhat more than the red ones; and thus, if no third lens was interposed, they would proceed in such lines as *l m n, l m n*. Now as the differently coloured rays fall upon the third lens with different degrees of divergence, it is plain, that the same power of refraction in that lens will operate upon them in such a manner as to bring them all together to a focus very nearly at the same point. The red rays, it is true, require the greatest power of refraction to bring them to a focus, but they fall upon the lens with the least degree of divergence.. The violet rays, though they require the least power of refraction, yet have the greatest degree of divergence, and thus all meet together at the point *x*, or very nearly so.

The achromatic effect may be produced by the union of one convex and one concave lens, but not so perfectly as with three lenses.

To proportion accurately the densities of the glasses to each other, requires much professional practice and attention. Experiments with the lenses after they are perfectly finished can alone be depended on. The essential parts of telescopes being few and cheap, the manufacture of them is frequently attempted by individuals for the purpose of amusement; and in every kind of telescope, but the achromatic, they have, with a due degree of perseverance, a fair hope of success. But in attempting to form an achromatic object-glass, however well they may think they have selected their glass, and proportioned the curvatures of the surfaces, they will be almost certain to find that a single set of lenses, when combined, produce an effect that disappoints their expectations. To succeed perfectly, they must therefore make, from different parcels of glass, a considerable number of lenses, with slight differences of curvature, and those must be selected which will bear the largest aperture and magnifying power. But this would render the undertaking, for the sake of one or two instruments, an Herculean labour, which would not bring to any private individual an adequate recompense, and which, from the number

of imperfect telescopes which are manufactured by those in the most extensive line of business, it would appear that opticians themselves do not fully enter into the spirit of. It has been very generally said and believed, that Dollond made his original experiments, and constructed those excellent three-foot glasses, (which at present bear so high a price, and are considered as inimitable,) with one single parcel of glass, which accidentally proved superior to any that has since been produced.—Nicholson has rendered it extremely probable that this is a vulgar error; the proprietor of the glass-house having assured him, that the original receipts and practice are still followed in the making of optical glass: that the principal opticians always complain of the bad quality of the glass, but never fail to take the whole quantity he makes at their request; and that, when they renew their orders, they always desire it may be exactly the same as the last. It seems therefore reasonable to conclude, that though different parcels of glass made according to the same formula, may differ a little, yet that as good glass for optical uses may be obtained now as formerly, and consequently as good telescopes, if the same great skill and disregard of expense which Dollond evinced, in adapting the curvatures of his lenses to each other and to the glass, were again brought into action.

The impossibility of obtaining perfectly homogeneous glass, and the consequent failure of producing that complete correction of the aberration of the rays of light in the telescopes called achromatic, induced Dr. Robert Blair to try the effects of fluid mediums; and his success was such as to induce him to give the term *aplanatic*, or, "free from error," to the object-glasses he thus constructed. He made a compound lens, consisting of a plano-convex of crown-glass, with its flat side towards the object, and a meniscus of the same materials, with its convex side in the same direction, and its flatter concave next the eye, and the interval between these lenses be filled with a solution of antimony in a certain proportion of muriatic acid. The lens thus constructed, did not exhibit the slightest vestige of any extraneous colour; still, the invention, after a lapse of more than twenty years, has not come into general use, probably from the difficulty of preserving any fluid from growing turbid in the course of time.

The Reflecting Telescope.

Mathematicians had demonstrated, that a pencil of rays could not be collected in a single point by a spherical lens; and also that the image transmitted by such a lens, would be in

some degree incurvated. Gregory, a young man of great abilities, was induced to believe that these inconveniences, and also the great length of refracting telescopes, would be obviated by substituting for the object-glass of the common telescope, a metallic speculum, of a parabolic figure, to receive the image, and to reflect it towards a small speculum of the same metal. This again was to return the image to an eye-glass placed behind the great speculum, which for that purpose was to be perforated in its centre. These ideas were published by Gregory in 1663, but as he possessed no mechanical dexterity himself, and could find no workman capable of realizing his invention, it might have sunk into oblivion, had not Sir Isaac Newton, in the course of his discoveries, found that the errors arising from the different refrangibility of light, were incomparably greater than those arising from reflection, and being himself as remarkable for manual skill, as geometrical knowledge, he was independent of others for the execution of his design. He therefore determined to try what could be done, and executed two reflecting telescopes, in 1672, on a plan somewhat different to what Gregory had proposed. Although a good metal for the speculum was not then known, although he had to contrive for himself the method of polishing it, and although his telescopes were but six inches long, yet in power, they were comparable to a six-feet refractor, and were capable of shewing Jupiter's satellites.

One great advantage of the reflecting telescope is, that it will admit of an eye-glass of a much shorter focal distance than a refracting telescope of the same length, consequently it will magnify so much the more. This advantage arises principally from the rays of light not being dispersed by reflection as they are by refraction, and partly from the practicability of giving the large reflectors a form either parabolical, or at least such as answers better than the spherical figure.

Gregorian Telescope.

This construction of the refle ng telescope, which is more common than any other, is represented by fig. 3, pl. VII. At the bottom of the tube ABCD, is placed the large concave reflector *k l*, with a circular hole through the middle of it in the direction of its axis. Within the tube of the telescope, and directly facing the perforation, is placed the small concave speculum, *g h*, supported by the arm *i*. Two lenses, *t t* and *q q*, are contained in the eye-tube LMNO, and the observer applies his eye to a small hole at *f*, in order to view the magnified image of the distant object YZ. The large reflector *k l*,

receives the rays from the distant object, and reflects them to its focus, where they form an inverted image, EF, in the manner already mentioned as one of the peculiar properties of a concave mirror. Diverging from the points of union, the pencils of rays proceed onwards, and cross each other a little before they reach the small mirror *g h*, the focus of which is at *n*, or a little further from the large speculum than its principal focus. From the small mirror, the rays are reflected somewhat convergently, and in that state are received before they meet by a plano-convex lens *t t*. By the action of this glass, their convergency is increased, and they form a second image, *a b*, which is erect like the object. This second image is magnified by the lens *q q*, through which the rays of each pencil pass nearly in a parallel direction to the eye; to exclude all extraneous light, the eye is applied to a very small hole, and sees the image under the angle *c f d*.

If the lens *t t*, were removed, the image would be formed somewhat larger at *r*, but the area or field of view would be smaller and less pleasant; for which reason it is not usual to omit the second lens. Sometimes the lens *q q*, is made double, for the reason assigned, in p. 486, in illustrating fig. 8, pl. V.

In this and other reflecting telescopes, containing two curved reflectors, it is necessary to have the power of altering the distance between the two mirrors. This is usually done by a wire, *e s*, passing along the outside of the tube, and with a screw at the end of it, which works in an external projection *w*, of the arm *i*, within the tube. The other end of the wire passes through a small stud affixed to the tube of the telescope at *m*; and the observer, while looking through the hole at *f*, turns the milled head *p*, of the wire, which is very near him, and thus regulates the distance of the small speculum as he finds requisite.

Newtonian Telescope.

A section of this telescope, is shewn by fig. 4, pl. VII. ABCD is the tube, which is open at the end AB, opposite the large speculum, *n o*. The large concave speculum, *n o*, is not perforated as in the last-mentioned instrument, but the small speculum, *q*, is set aslant, so as to direct the rays received from the large speculum through an aperture, *g*, at the side of the tube, where they are received and refracted to the eye by a lens or lenses in a tube *h*. The speculum *q*, is suspended within the tube, by an arm, *p*, with its centre opposite the centre of the speculum *n o*; it is not curved, but plane, and has therefore no other effect than that of changing the direction of the rays.

Without the small reflector, the rays from the large speculum would be converged at R, and the observer might have an eye-glass placed to view the image formed there, with his face towards the speculum *n o;* but in this case his head would intercept the greatest part of the rays, unless the instrument was very large.

The Newtonian telescope, as first described, is very convenient for viewing objects in the zenith; as they may be seen while the observer retains his ordinary position of looking forward horizontally.

Herschel's Telescope.

The best and most powerful telescopes ever constructed, have been made by Dr. Herschel, who is so well known by his labours, as one of the most eminent astronomers of the present day. The astronomers of the Continent have adopted a phraseology, which contains a very extraordinary acknowledgment of the value of his telescopes; when they wish to convey the highest possible idea of the excellence of a telescope, they assert that it is equal to one of Herschel's.

The largest reflecting telescope now existing was made by Dr. Herschel. It is forty feet in length, and the polished surface of the large speculum is four feet in diameter. It has no second reflector, a circumstance that adds much to the brightness of the objects viewed in it. The observer, who looks through an eye-glass, as in other telescopes, has of course his back to the objects; but it is so contrived that little or no light is intercepted by this means. We may use the diagram of the Newtonian telescope, fig. 4, pl. VII, to illustrate the position of the observer more particularly. Supposing the speculum *q*, and its support to be removed, the rays *n o*, as before observed, would be converged to R; but if the observer were placed there, he would intercept a large portion of the light, even when facing this gigantic telescope; suppose then the upper part *n*, of the speculum, to incline downwards, that is, to be set at an angle to the axis of the tube, the rays may be directed to S, or any other point nearer the tube, where the spectator may be placed, and will occasion no sensible dimness of the image thrown by a large mirror. In Herschel's forty-feet telescope, the converging rays reflected by the mirror, pass the extremity of the tube at the distance of four inches, and come into the air; so that the observer scarcely at all interferes with the incident light, as the diameter of the tube exceeds that of the mirror about ten inches. It will bear a magnifying power of six thousand times the diameter of an object.

Cassegrainian Telescope.

This telescope differs from those of the Gregorian and Newtonian construction, in having the small reflector convex instead of concave; in consequence of which the small reflector must be placed nearer to the large reflector than the focus of the latter. It shews objects inverted, because the rays do not cross, and no image is formed between the two reflectors; but with the same magnifying power, it is shorter than the Gregorian, by twice the focal length of the small mirror.

Of the Magnifying Power of Telescopes.

The magnifying power of a telescope is constituted by the difference in size between the object viewed by the naked eye, and the image seen in the field of view of the instrument; and this difference may be expressed in three different ways: 1, we express the effect of the telescope on the apparent increase of the *diameter* of objects; 2, on the *superficies;* and 3, on the *solidity* or *cube* of the objects. But it has been generally agreed to express the magnifying power of telescopes by the effect they produce on the diameter only of objects; this mode of expression conveys clearer ideas of the power of the instrument than any other, and is always understood to be meant when the contrary is not expressed. Hence, if a telescope shews an object, at the distance of 100 yards, as large as that object would appear to the naked eye at the distance of one yard, it is understood to magnify one hundred times.

The magnifying power of the astronomical telescope, or the night-glass, is as the focal distance of the eye-glass to the focal distance of the object-glass; therefore, if the latter be divided by the former, the quotient will express the magnifying power. The power of the perspective-glass may be estimated in the same way; for the two additional eye-glasses are not employed to change the magnifying power, being equal in focal distance to the third, but only to produce the erect position of objects; by dividing the focal distance of one eye-glass by the focal distance of the object-glass, the true power is therefore obtained.

In the Galilean telescope, the virtual focus of the concave or eye-glass, must be divided by the real focus of the object-glass.

To find the magnifying power of the Gregorian telescope, multiply the focal distance of the great mirror by the distance of the small mirror from the image next the eye; and multiply the focal distance of the small mirror by the focal distance of

the eye-glass; then divide the product of the former multiplication by the product of the latter, and the quotient will express the magnifying power.

The magnifying power of the Newtonian telescope, or of Herschel's, is found by dividing the focal distance of the large speculum by the focal distance of the eye-glass.

The magnifying power of the Cassegrainian reflector is the same as that of the Gregorian, when their respective specula are of equal curvature.

As it is often inconvenient, and sometimes impossible without injuring the instrument, to ascertain with precision the foci of the lenses and mirrors, it is advantageous to possess the means of ascertaining the magnifying power of a telescope experimentally. This may be done in several ways, of which the following is the one recommended by Edwards:

At the distance of 100 or 200 yards from the telescope, put up a small circle of paper, of any determinate diameter, an inch for instance. Upon a card, or any piece of strong paper, through which the light cannot be easily transmitted, draw two black parallel lines, the distance of which from each other is exactly equal to the diameter of the small circle. Adjust the telescope to distinct vision, and through it view the small circle with one eye, and with the other eye, open also, view at the same time the two parallel lines. Let the parallel lines be then moved nearer to, or farther from the eye, till you see them exactly to cover the small circle viewed in the telescope. Measure now the distance of the small circle, and also of the parallel lines, from your eye; then divide the distance of the former by that of the latter, and you will have the magnifying power of the telescope.

Miscellaneous Remarks relative to Telescopes.

In treating of vision, we observed, that objects seen with both eyes at once, appear more vivid than they do to either eye singly. This fact gave rise to what is called the binocular or double telescope, in the use of which the phenomenon is very obvious. This instrument sonsists of two equal telescopes, fastened together, and made to point to the same object. They must be at the same distance from each other as the pupils of the eyes of the observer, who must look through both the telescopes at once, by which means objects will appear brighter, and somewhat larger, than when only one telescope is used, though the magnifying power is the same in both cases. The inconvenience of managing the binocular telescope, seems, however, to be the cause of its being disused.

Miscellaneous remarks relative to telescopes.

Valuable telescopes are usually furnished with what is called a *finder*, which is nothing more than a short telescope, and is generally affixed to the tube of the large telescope, as at G, fig. 3, pl. VII. It is used for the purpose of bringing an object expeditiously into the field of the large telescope. It magnifies but little, seldom more than six or eight times; but it has a very extensive field of view, so that any given object is easily comprehended within it. In the inside of its tube, and exactly at the focus of the eye-glass, there are two slender wires, which cross each other in the axis of the telescope. Now the finder is so adjusted, that when an object seen through it appears to be near the crossing of its wires, it is at the same time visible through the great telescope, and by this means much time is saved, especially to unpractised observers.

Both refracting and reflecting telescopes, of the best sort, are furnished with two or more different eye-pieces, in order that a greater or less power may be employed, as the occasion appears to require.

In every telescope, the distance between the eye and the object-glass must be alterable, in order to suit different eyes, or render objects, at different distances, distinctly visible to the same eye.

The following observations on another adjustment, of which telescopes ought to be susceptible, are from the first volume of Nicholson's Journal, 4to series: "Every attentive observer must have taken notice, that light is of as much consequence to artificial vision as magnifying power. It may therefore afford matter of surprise, that the most variable of all adjustments of the eye, viz. that of aperture, should never be introduced into our artificial combinations. Distant woods, and other land objects, are invisible to a high magnifying power, for want of light, when the same objects may be distinctly seen with a lower. By means of an artificial iris, which an ingenious artist will find little difficulty in contriving, this disadvantage in telescopes might be obviated. Suppose a brass ring to surround the object end of the telescope, and upon this let eight or more triangular slips of brass be fixed, so as to revolve on equidistant pins passing through each triangle near one of its corners. If the triangles be slidden in upon each other, it may readily be apprehended that they will close the aperture; and if they be all made to revolve or slide backwards alike, it is clear that their edge will leave an octagonal aperture, greater or less, according to circumstances. The equable motion of all the triangles may be produced either by pinions and one toothed wheel, or by what is called snail-work. Another kind of iris, more compact, may be made by causing thin elastic

slips of brass to slide along parallel to the tube, and be conducted through a slit in a brass cap, which will lead them across the aperture in a radial direction."

To stop the wandering rays which would tend to confuse the image of a telescope, a plate of metal, which has a small round hole in the middle of it, is placed in the tube containing the eye-glasses, parallel with them. It is called the diaphragm, and is generally fixed within the telescope, at the focal distance of the glass nearest the eye. By this means, the field of view is lessened, but the advantage of greater distinctness is obtained.

To ascertain the goodness of object-glasses, the best expedient is, to place them successively in a tube, and examine some distant object with different eye-glasses; that glass which represents objects the brightest and most distinct, and which bears the greatest aperture with the shortest eye-glass, without colouring, is the best.

In double convex lenses, the most perfect is that whose radius of curvature of the first surface, is to that of the second as one to six; its aberration being the least possible, viz. $\frac{15}{14}$ of its thickness: but if this glass is turned with its other side to the rays, the aberration will be $\frac{45}{12}$, and therefore would be much worse. The same ratio holds with respect to concave lenses.

The lenses of a good telescope should all be perfectly well polished, and should be as thin as possible for their size and curvature. When a lens is exactly circular, and yet is found to be thicker on one side than another, it is a proof that the axes of the two surfaces are not coincident, and it ought to be rejected.

Of reflecting telescopes, the Gregorian is almost the only one made for common use. This preference seems to be owing to the neatness of its appearance, and to its being pointed towards objects in the same manner as refracting telescopes, rather than to any really intrinsic advantages which it has over the Newtonian construction. In all the reflecting telescopes we have noticed, the diameter of the large mirror, on account of the interposition of the small one, at the aperture, must be greater than would otherwise be required, in order to enlighten the field of view sufficiently; and it may also be observed, that as specula have probably never been ground to a truly parabolic figure, the central part, the benefit of which is lost, is the most valuable portion of the whole, because it would reflect the light with the greatest regularity. To this it may be added, that the difficulty of grinding a speculum increases perhaps in so great a proportion as the square of the diameter, and it is therefore of some importance to those who

may undertake the construction of these instruments for themselves, to make the large speculum as small as possible, consistently with a given power and quantity of light. We shall therefore mention the form of a reflecting telescope, which we recollect to have been shewn many years ago, by a self-taught optician, who, so far as we can recollect, on the question being put to him, declared himself to be the first who had adopted it. It is represented by fig. 5, pl. VII, where the great mirror is as usual at the bottom of the principal tube, but instead of having its axis coincident with that of the tube, it is inclined, so as to throw the image upwards, through an aperture for that purpose, to *n o*, whence the rays diverge, and falling upon the small speculum, are reflected by it to the eye, as in the Gregorian telescope. Here we have supposed the small mirror to be concave, but we are not certain whether it was so or not; it is clear, the principle of it is preserved, if the whole diameter of the mirror is employed to reflect light; and therefore it may have the small mirror convex like Cassegrain's reflector, or plane, like Newton's. We can speak with confidence of the excellence of the instrument we allude to, and we gladly bear this testimony to the merit of an obscure individual, who, we have reason to believe, is now deceased. He was tenacious of his optical knowledge, and reserved in speaking of it; yet he was far from an illiberal character. His mirrors were cast by himself in his own house, and every other part of the workmanship of his instruments, and the tools with which they were made, were constructed by himself: in solitude and silence, by day and by night, though surrounded by the chilling difficulties of poverty, he seems to have pursued his studies with an assiduity seldom paralleled; and the knowledge which it cost him so much to acquire, he might feel it difficult to part with to a casual acquaintance. Perhaps the notice we have taken of him in this place, may be more than is called for by any proof we have given of his abilities, in the new arrangement of a telescope; but the example may be an encouragement to others, and ought not to be lost. In another place, we may have an opportunity of disclosing his name, and of investigating his particular merits; here we will only add, that he had taken no scanty draught of the "Pierian spring," and that his poetical effusions were as elegant and impassioned, as the work of his hands was correct and effectual.

The two mirrors of a telescope should not have the same curve. Maskelyne has observed, that when the two specula are parabolas, they cause a very considerable aberration, which is negative, that is to say, the focus of the extreme ray is

longer than those of the middle ones. If the large speculum is a parabola, the small one ought to be an ellipse; but when the small speculum is spherical, which is generally the case in practice, if concave, the figure of the large speculum ought to be an hyperbola; if convex, the large speculum ought to be an ellipse, to free the telescope from aberration. This will be easier understood, by attending to the positions of the first and second images; when a curve is of such a form that lines drawn from each image, and meeting in any point of the curve, make equal angles with the tangent to the curve at that point, it is evident that such curve will be free from aberration.

From a property of reflecting telescopes, that the apertures of the two specula are to each other very nearly in the proportion of their focal lengths, it follows that their aberrations will be to each other in the same proportion; and these aberrations are in the same direction, if the two specula are both concave; or in contrary directions, if one speculum is concave, and the other convex.

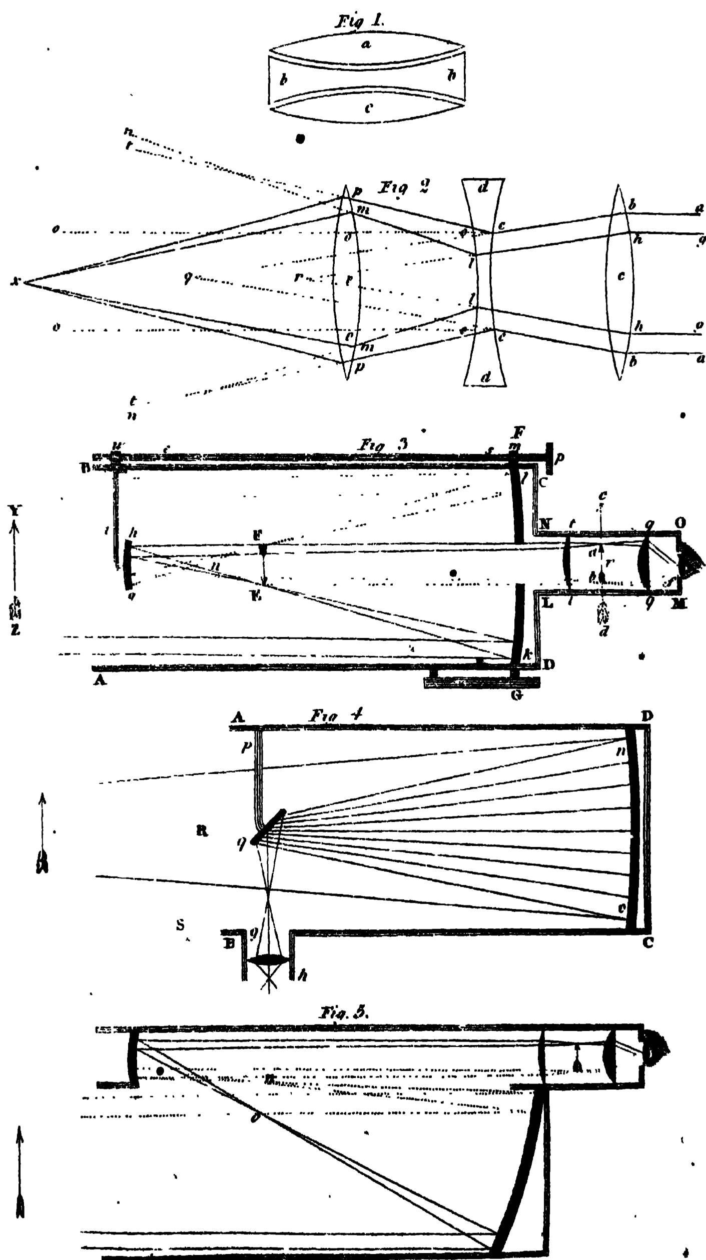
In the Gregorian telescope, both specula being concave, the aberration at the second image will be the sum of the aberrations of the two mirrors; but in Cassegrain's construction, one mirror being concave, and the other convex, the aberration at the second image will be the difference between their aberrations. By assuming such proportions for the foci of the specula as are generally used in the reflecting telescope, which is about as 1 to 4, the aberration in the Cassegrainian construction will be to that in the Gregorian as 3 to 5. Hence appears the service which might be rendered to artists by a complete mathematical investigation of the curves adapted to optical purposes.

Of Micrometers.

A micrometer is an instrument by which the apparent magnitudes of objects viewed through microscopes or telescopes are measured.

A great variety of micrometers have been contrived, some of which are very complicated and expensive, others possess great simplicity. The accuracy of their performance has not always been proportionate to their cost. We shall notice only one or two of the most simple micrometers, as our limits will not permit us to enlarge much beyond what may prove interesting to the generality of our readers.

Lewenhoeck's method of estimating the size of small objects was by comparing them with grains of sand, of which one hundred placed in a line took up an inch. These grains he laid on the same plate with his objects and viewed them at the


Fig 1.
Fig 2
Fig 3
Fig 4
Fig. 5.

same time. Dr. Jurin's method was similar to this, for he wrapped a piece of fine silver wire very closely round a pin, and observed how many rings made an inch; and he used this wire as Lewenhoeck used his sand. Dr. Hook used to look upon the magnified object with one eye, while, at the same time, he viewed other objects placed at the same distance, with the other eye. In this manner he was able, by the help of a ruler, divided into inches and small parts, and laid on the pedestal of the microscope, to cast the magnified appearance of the object upon the ruler, and thus exactly to measure the diameter which it appeared to have through the glass; which being compared with the diameter as it appeared to the naked eye, easily shewed the degree in which it was magnified. A little practice renders this method very easy.

Cavallo's micrometer, which he has described in the third volume of his "Elements of Natural and Experimental Philosophy," is simple and valuable. It consists of a small semi-transparent scale or slip of mother-of-pearl, about the twentieth part of an inch broad, and of the thickness of common writing paper. It is divided into a number of equal parts by means of parallel lines, every fifth and tenth of which divisions is a little longer than the rest.

This micrometer, or divided scale, is situated within the tube, at the focus of the eye-lens of the telescope, where the image of the object is formed, and with its divided edge passing through the centre of the field of view; though this is not absolutely necessary. It is immaterial whether the telescope be a refractor or a reflector, provided the eye-lens be convex, and not concave, as in the Galilean telescope.

The simplest way of fixing it, is to stick it upon the diaphragm, which generally stands within the tube, at the focal distance of the eye-lens.

By looking through the telescope, the image of the object and the micrometer will appear to coincide: hence the observer may easily see how many divisions of the latter measure the length or breadth of the former; and knowing the value of the divisions of the micrometer, he may easily determine the angle which is subtended by the object.

There are several methods of ascertaining the value of the divisions of a micrometer in a given telescope. The following is one of the easiest: Direct the telescope to the sun, and observe how many divisions of the micrometer measure its diameter exactly; then take out of the Nautical Almanack the diameter of the sun for the day in which the observation is made; divide it by the above-mentioned number of divisions, and the quotient is the value of one division of the micrometer.

Thus, suppose that 26½ divisions of the micrometer measure the diameter of the sun, and the Nautical Almanack gives for the measure of the angle which is subtended by the same diameter, 31 minutes, 22 seconds; or (by reducing the whole into seconds) 1882 seconds. Divide 1882 by 26.5, and the quotient, neglecting a small remainder, is 71 seconds, or 1 minute 11 seconds; which is the value of one division of the micrometer; and therefore the value of any greater number of divisions is easily ascertained.

The mother-of-pearl micrometer may be applied to a microscope, and it will thus serve to measure the lineal dimensions of the object. The value of its divisions may be ascertained by placing an object of a known dimension before the microscope, and by observing how many divisions of the micrometer measure its magnified image. For instance, place a piece of paper which is exactly one-tenth of an inch long, before the microscope, and if you find that 50 divisions of the micrometer measure its magnified image, you may conclude that each division denotes an extension of the 500dth part of an inch in the object; for if 50 divisions measure one-tenth, 500 divisions must measure the whole inch.

Mother-of-pearl was found, by Cavallo, after many trials, to be a much more convenient substance than either glass, ivory, horn, or wood, as it is a very steady substance, the divisions are easily marked upon it, and when made as thin as common writing paper, it has a very useful degree of transparency.

Abstract of Optics.

1. The particles of light, which are inconceivably small, proceed from luminous bodies in right lines.

2. Consequently the density of light is inversely as the square of the distance from the luminous centre.

3. Light moves at the rate of nearly 200,000 miles in one second of time.

4. Its impression on the retina is not instantaneous; hence though its particles may be separately projected, so as to be, in their progress, at the rate of 1000 miles apart, its velocity is sufficient to produce distinct vision.

5. Every ray of light carries with it the image of the point from which it was emitted; when, therefore, pencils of rays

from every point of an object are united in the same order in which they were emitted, they form an image or representation of that object, at the place where they are thus united.

6. All the rays of light, which enter another medium obliquely, suffer refraction; that is, they either move farther from, or nearer to, the perpendicular, as the medium into which they enter is rarer or denser than the other medium.

7. On the refrangibility of light depends the properties of lenses.

8. Convex lenses collect the rays of light, and make them converge to a centre or focus.

9. Concave lenses disperse the rays of light, their power of refraction not being towards their centre, but towards their circumference.

10. When light strikes upon a surface, it is reflected so that the angle of reflection is equal to the angle of incidence; on this the properties of mirrors depend.

11. Plane mirrors have no other effect than that of changing the direction of the incident rays.

12. Convex mirrors cause parallel rays to diverge.

13. Concave mirrors collect parallel rays, or cause them to converge to a focus.

14. Mixed mirrors exhibit distorted images, because they increase or lessen the divergence or convergence of the rays in one or two directions only.

15. The solar beam is composed of rays possessed of different degrees of refrangibility, and these differences of refrangibility, which are dependent on the size of their particles, produce all the phenomena of colours.

16. The solar beam, or white light, contains rays of seven different colours, viz. red, orange, yellow, green, blue, indigo, and violet. These are called the primitive colours, because they are immutable, except by intermixture.

17. It is inferred that red light is composed of particles of the largest size, because it is found to be capable of struggling through thick and resisting mediums, which stop every other colour.

18. The size of the particles of other colours are in the order of their enumeration, the violet being the smallest.

19. The rainbow is owing to the separation of the light into its primitive colours, by the drops of falling rain, which act like a prism.

20. The rays of light are *inflected* when they pass very near a body, and *deflected* when they pass at a greater distance.

21. Those rays which deviate the least by refraction, deviate the most by flection.

22. The images of all visible objects are depicted on the retina, in an inverted position.

23. With two eyes, vision is not only more distinct, but more accurate than with one.

24. A good eye can see most distinctly when the rays fall parallel upon it, because the foci of such rays fall exactly on the retina.

25. The best eye can hardly distinguish any object that subtends an angle of less than half a minute.

26. The apparent magnitude of objects is dependent on the angle under which they are seen, or on the size of their images depicted on the retina.

27. The long-sighted require convex spectacles, the short-sighted, concave ones.

28. Burning lenses must be convex, and burning mirrors concave, as the effects of both these instruments are dependent on the condensation of the incident light.

29. Microscopes are instruments for viewing small objects. They appear to magnify objects, because they enable us to see them with distinctness, nearer than the natural limits of vision.

30. Refracting telescopes are formed by lenses only; when manufactured in the best manner, they are either furnished with an *achromatic* object-glass, which corrects the defect arising from the unequal refraction of the different rays, by a combination of one or two convex lenses with a concave one of a different sort of glass; or though more rarely, they have an *aplanatic* object-glass, which corrects the same defect by the combination of a plano-convex and meniscus glass, with a fluid between them that acts like a third lens.

31. Reflecting telescopes consist of lenses and at least of one speculum. When there is more than one speculum, the second is only about one-fourth of the size of the other, and may be either convex, concave, or plane.

32. Reflecting telescopes admit of a much greater magnify ing power in a given length, than refracting telescopes.

33. The binocular telescope consists of two telescopes so combined, that both eyes may be employed in looking at the same object.

ASTRONOMY.

ASTRONOMY is the science which treats of the motions, eclipses, magnitudes, periods, and other phenomena of the heavenly bodies.

The early history of astronomy, as of all other ancient sciences, is enveloped in much obscurity. It may be presumed, that some knowledge of it would be nearly coeval with the human race, because it would excite attention, as well from motives of curiosity, as from its connection with the common concerns of life; but in what age or country the united observations of many, were first so far methodized, as to raise it to the dignity of a science, is now beyond the reach of unquestionable discovery, and it would be useless to multiply conjectures on the subject.

Those delightful regions of Asia, which were the first abodes of mankind, were peculiarly calculated to favour the growth of astronomical knowledge. Accordingly, it appears that astronomy was much cultivated among the Chaldeans. The level and extensive plains of that country, the nights which they passed in the open air, an unbroken horizon, a pure and serene sky, all conspired to engage that people to contemplate the motions of the stars, and to lead them to conjecture on the laws by which they were governed.

From Chaldea, astronomy passed into Egypt, and was soon afterwards carried into Phœnicia, where the people began to apply the observations which had been made to the uses of navigation, and thus rendered themselves the masters of the sea and of commerce. Their guide in steering their ships, when far from land, was one of the stars in the constellation called the Little Bear, which, unlike other stars, appeared always to retain the same situation. Other nations, less skilful in astronomy, observed only the Great Bear in their voyages, a guide too imperfect to enable them to lose sight of land with safety.

Thales, the Milesian, who flourished about 700 years before the Christian era, brought the science of the stars from Phœnicia into Greece, where he taught the utility of the constellation of the Little Bear in navigation. He also taught the theory of the motion of the sun and moon, by which he accounted for the length and shortness of the days, determined the number of the days of the solar year, and not only explained the cause of eclipses, but the art of predicting them, which he even reduced to practice, foretelling an eclipse which took place soon after, and was rendered memorable by its happening on a day of battle between the Medes and Lydians.

To Anaximander, one of the disciples of Thales, is ascribed the invention of the terrestrial globe, and of a gnomon which he erected at Sparta, by means of which he observed the equinoxes and solstices, and determined the obliquity of the ecliptic more exactly than had ever been done before. The Greeks, assisted by the instructions they had received from Thales and Anaximander, ventured to make considerable voyages, and planted several colonies in remote countries; yet the latter philosopher and his children were proscribed by the Athenians, and their lives would have been sacrificed but for Pericles, through whose influence the sentence was commuted for banishment. The charge against him was the discovery of truth; for it was thought impious to suppose the works of the gods subject to immutable laws!

Pythagoras, another of the disciples of Thales, taught many sublime astronomical truths. To him is attributed the discovery of the true system of the world, which, after the lapse of many centuries, was revived by Copernicus, and which is now settled on the basis of so many proofs, that it can never be overthrown. It was even thought, in his school, that the planets were inhabited like the earth, and that the stars which are disseminated through infinite space, are suns, and the centres of other planetary systems. He is also said to have considered the comets as permanent bodies, moving round the sun; and not as perishing meteors, formed in the atmosphere, as they were thought to be in after times. Pythagoras died about the year 497 before Christ.

Pythias was the first who taught the method of distinguishing climates by the length of the days and nights, and about his time, a remarkable emulation to excel in astronomy prevailed among the Greeks. Eudoxus, a disciple of Plato, not satisfied with what he could learn at Athens, repaired to Egypt, to cultivate astronomy at its source. At his return he compiled several books on astronomy, and among others, a description of the constellations. Eudoxus attempted to explain the celebrated cycle of nineteen years, which had been imagined by Meton, in order to conciliate the solar and lunar motions. This is the most accurate period, for a short interval of time, that could have been devised, for embracing an exact number of revolutions of the sun and moon; and is so simple and useful, that when Meton proposed it to the Greeks, assembled at the Olympic games, as the basis of their calendar, it was received with great approbation, and unanimously adopted by all their colonies. The year of the cycle is called the golden number, and is still placed in the calendar.

Aristotle, the disciple of Plato, and the contemporary of Eudoxus, made use of astronomy for improving physics and geography. He attempted to determine, by astronomical observations, both the figure and the magnitude of the earth. He demonstrated that it was of a spherical form, by the circular appearance of its shadow on the disc of the moon in eclipses; and from the inequality of the meridian altitudes of the sun, which are different in different latitudes. Callisthenes, who attended Alexander the Great, having been sent to Babylon, found there astronomical observations made by the Babylonians during the space of 1903 years, and sent them to Aristotle.

But of all the schools of antiquity in which astronomy was taught, that of Alexandria has justly attained the highest celebrity. Here we have the first record of a combined series of observations, made with instruments proper for measuring angles, and calculated trigonometrically. Here the position of the stars began to be minutely determined; the course of the planets to be traced with care; and the inequalities of the solar and lunar motions to be better known. The theory adopted, aimed at the explanation of all the celestial motions; and though inferior to that of Pythagoras, yet the numerous observations which were made, furnished the means of detecting its fallacy, and of enabling succeeding astronomers to discover the true system of nature.—Hipparchus of Bithynia, who flourished at Alexandria about the year 162 before Christ, is particularly famous for the excellence of his observations; and he determined the length of the tropical year with a precision never attained before, his result not varying more than 4½ minutes from the truth.

Ptolemy, an Egyptian, who has always been considered the prince of astronomers among the ancients, flourished in the second century of the Christian era. He has preserved and transmitted to us the observations and principal discoveries of the ancients, much enriched and enlarged by his own labours, in a treatise called "The Great Syntaxis," in which he gave the theory and tables of the motion of the sun and moon, the planets and the fixed stars. He adopted the most ancient system, which supposed the earth to be in the centre of the universe, and this system, to distinguish it from others, has been called the Ptolemaic System. The defects of his system did not, however, prevent him from calculating all the eclipses that were to happen for 600 years to come.

About the year 826, Ptolemy's great work was translated by the Arabians into their language, in which it was called the

Almagest. About the year 1230, it was translated from the Arabic into Latin, under the auspices of the emperor Frederic II. who was willing that the Christians should understand astronomy as well as those whom they styled Barbarians. Alphonso, king of Castile, went further, for he assembled the most able astronomers from all parts, who composed new tables, called after him the Alphonsine tables.

By these means the attention of the learned men in Europe became directed to a science, the knowledge of which promised so much gratification, utility, and fame. Calculations and treatises became very frequent, as well as the invention of instruments to facilitate observations. The most memorable event of this period was the revival of the ancient or Pythagorean system of the world, which had been set aside ever since the time of Ptolemy. This was done by Nicholas Copernicus, a native of Thorn, in Prussia, born in 1472. The Ptolemaic system, which supposes the earth to be fixed in the centre of the universe, and the Sun and Moon, with Mercury, Venus, and the other planets, to revolve about it in concentric circles, he perceived to be inconsistent with the phenomena, and encumbered with many absurdities which did not affect the hypothesis which considered the Sun to be in the centre, and the Earth a planet revolving annually with the rest about the Sun, and daily on its own axis. He established his theory by such incontrovertible reasoning, that it gradually prevailed from that time, and continuing to spread with the lapse of ages, it is now the only one received in Europe, and wherever true science is known. But Copernicus had not himself the satisfaction of seeing the triumph of the theory he defended: threatened with persecution by the religious bigots on one side, and with a perverse opposition from those who called themselves philosophers on the other, he could not be prevailed upon to publish the work which contained the result of his observations, till long after it had been finished. His consent to the publication of it was wrung from him by the importunities of his friends, and a copy was brought to him only a few hours before his death, which happened in his seventy-first year. In this age, or rather in this country, we regard with astonishment the degrading thraldom to which the human mind was in these times subjected.

The only opposition of any consequence which the theory of Copernicus ever met with from science and argument, proceeded from Tycho Brahe, a celebrated Danish astronomer, who attempted to set up against it a theory of his own.—His system is not very different from the Ptolemaic, but is generally called by his name. He supposed the earth to be

immoveable in the centre of the universe, and the Sun to revolve about it every twenty-four hours: the planets he thought went round the Sun in their periodical times, Mercury being nearest to the Sun, then Venus, Mars, Jupiter, and Saturn, and of course to revolve also about the earth. But some of Brahe's disciples supposed the earth to have a diurnal motion round its axis, and the sun, with all the planets, to move round the earth in one year. The inconsistencies with which this hypothesis abounded, will be most obvious when we have explained the Copernican or true system. In defence of Brahe's just fame, it is proper to add, that though he adopted an erroneous theory, he was actuated by pious motives, and that he rendered very important services to astronomy, by the correctness and number of his observations.

Kepler was one of the pupils of Tycho Brahe, and a man of a truly original and admirable genius. Hipparchus, Ptolemy, Tycho Brahe, and even Copernicus himself, were indebted for a great part of their knowledge to the Egyptians, Chaldeans, and Indians; pursuing paths already pointed out, they did little more than separate fancy from fact, with more or less success; but Kepler, by his own talents and industry, has made discoveries of which no traces are to be found in the annals of antiquity. Galileo was contemporary with Kepler, and while the latter was tracing the orbits of the planets, and settling the laws of their motions, he was investigating the doctrine of motion in general, which had been neglected for 2000 years; and from the results of their united labours, Newton and Huygens were afterwards enabled to establish the most complete theories of all the planetary motions. Though Galileo proved, in the most incontestable manner, the annual and diurnal motion of the earth, his doctrine was declared heretical by a congregation of cardinals assembled for the purpose, and though not only venerable for his years, but also one of the most virtuous and enlightened men of his age, he was condemned to perpetual imprisonment, for believing and promulgating truths which accorded with the order of nature, and which he therefore believed to be written with the finger of God. Through the solicitations of his great patron, the Grand Duke of Tuscany, he partially regained his liberty at the end of a year, and in 1642 he died, regretted by the learned and liberal of all Europe.

From the time of Newton, who carried the theoretical part of the science to perfection, astronomy has never been without an illustrious phalanx of supporters, whose particular merits and discoveries it would be impossible to mention in this concise historical abstract. We shall now therefore proceed with the elementary details of the science.

Definitions and preliminary Explanations.

All the visible bodies which are dispersed throughout the whole heavens, receive in ordinary discourse the appellation of *stars;* but they are divided by astronomers into several classes, according to certain differences which distinguish them.

The *fixed stars*, or *simple stars*, are so called because they always appear to be at the same distance from each other. The sun is a fixed star, its apparent motion being occasioned only by that of the earth, and all the other fixed stars are supposed to be suns, which to us appear small, on account of the immensity of their distances from us. Another property supposed to be peculiar to the fixed stars, is, that they shine by their own light.

The term *planet* is derived from a Greek word signifying wanderer, and is given to those stars which are continually changing their position with respect to each other, as well as with respect to the fixed stars.

Dr. Herschel more particularly defines planets to be celestial bodies of a considerable size and small eccentricity of orbit, moving in planes that do not deviate many degrees from that of the earth, in a direct course, and in orbits at considerable distances from each other, with atmospheres of considerable extent, but bearing hardly any sensible proportion to their diameters, and having satellites or rings.

The planets are further distinguished into *primary* and *secondary*. The primary ones, called, by way of eminence, planets, are those which revolve round the sun as a centre: and the secondary planets, more usually called *satellites* or *moons*, are those which revolve round a primary planet as a centre, and constantly attend it in its revolution round the sun.

The primary planets are again distinguished into *superior* and *inferior*. The superior planets are those farther from the sun than our Earth, as Mars, Jupiter, Saturn, and the Herschel: and the inferior planets are those nearer the sun than our Earth, as Venus and Mercury.

The newly discovered planets, Ceres Ferdinandea, Juno, Pallas, and Vesta, and all such as may hereafter be discovered, and found to resemble them, Dr. Herschel proposes to call by the name of *asteroids*, which he defines as celestial bodies, moving in orbits either of little or of considerable eccentricity round the sun, the plane of which may be inclined to the ecliptic in any angle whatsoever. This motion may be direct or retrograde; and they may or may not have considerable atmospheres, very small comas, discs, or nuclei.

Comets are celestial bodies moving in directions wholly

undetermined, in very eccentric orbits, situated in every variety of position, and having very extensive atmospheres.

Planets, satellites, asteroids, and comets, all shine by reflected light.

The planets, for the convenience of expressing them on globes, or in tables, &c. are often denoted by peculiar characters, as follows: Mercury ☿; Venus ♀; the Earth ⊕; Mars ♂; Jupiter ♃; Saturn ♄; and the Georgium Sidus, or Georgium Planet, which the foreign astronomers usually call Uranus, or Herschel ♅. The four lately discovered planets, or asteroids, have not yet any peculiar characters assigned to them.

The *orbit* of a planet or comet, is its path, or the curve it describes in its revolution round its central body. The orbits of all the planets are elliptical, yet they deviate but very little from circles; while the orbits of comets deviate widely from circles, and are therefore said to have great eccentricity.

The *direct motion* of a planet, is when it appears to move from west to east. Its *retrograde motion*, is when it appears to move the contrary way, that is, from east to west. When a planet seems to remain a certain time in the same place, it is said to be *stationary*.

The *ecliptic* is that path or way which the earth appears to describe among the fixed stars, to an eye placed in the sun; or, which amounts to the same thing, it is the path which the sun appears to describe among the stars, to an eye on the earth.

The *zodiac* is a zone extending eight degrees on each side of the ecliptic all round the heavens. It is divided into 12 equal parts, called signs; and as every circle, whether great or small, is supposed to be divided into 360 degrees, each sign of the zodiac contains 30 degrees.

Each sign of the zodiac is distinguished by a particular name, and each name is denoted by a particular symbol, which is sometimes used alone. These names and symbols are as follows: Aries ♈; Taurus ♉; Gemini ♊; Cancer ♋; Leo ♌; Virgo ♍; Libra ♎; Scorpio ♏; Sagittarius ♐; Capricornus ♑; Aquarius ♒, and Pisces ♓. The signs of the zodiac are situated in the order in which they are here enumerated, reckoning from west to east, which is called the *order of the signs*.

The fixed stars are divided into groups, called *constellations*, which comprise a number of stars that appear to be near each other. The ancients distinguished the constellations by the names of men, birds, fishes, &c. such a name being selected, that the stars of the constellation it is given to, could be contained within a figure of the original. Then, in order to specify any particular star, they spoke, for instance, of the star on the

shoulder of Orion, or on the tail of the Fish, &c. The assistance these imaginary figures afford the memory, has induced the moderns to continue the use of them, with some improvements. They use these constellations to indicate the general assemblage of stars in a certain portion of the heavens; but they distinguish each particular star by a Greek letter or by figures, as, 1, 2, 3, &c. and mark its true place by mentioning its distances from particular points.

The *horizon* is either *sensible* or *rational:* the sensible horizon is that circle which limits our view; the rational or true horizon is parallel to the former, and is a circle in the heavens supposed to be formed by the continuation of a plane which passes through the centre of the earth. The planes of these two horizons, are separated by the earth's semi-diameter, but with respect to the heavens, they may be considered as coincident, the distance of the fixed stars being so prodigiously great, that the error of considering the earth's semi-diameter as a point, is insignificant.

The whole concave orb or expanse which invests our globe, and in which the heavenly bodies are seen, is called the sphere.

The sphere appears to turn round two points which are opposite each other, and are called the *poles of the world,* one of them being called the *arctic,* or *north pole;* and the other the *antarctic,* or *south pole.* The axis itself, or that imaginary line which joins the two poles, is called the *axis of the world.*

The highest point of the heavens, or that directly over our heads, is called the *zenith.*

The opposite, or lowest point of the heavens, which is directly under our feet, is called the *nadir.*

The *nodes* are the two points in which the orbit of a planet intersects the ecliptic. That node from which the planet ascends northward, above the plane of the ecliptic, is called the *ascending node;* the other node, from which the planet descends southward, is called the *descending node.* A line passing from one node to the other, is called the *line of nodes.*

The orbit of each planet being an ellipse, in one focus* of

* The nature of the foci of an ellipse is well shewn by the common mechanical method of describing that figure: two pins or nails are driven far enough into a board to bear a slight pressure; a cord with its two ends fastened together, so as to form what is, in the arts, called an endless cord, is then put over them; and a pencil or any marking instrument is employed to stretch one point of the cord parallel to the board, and at the same time to mark out its own course, while the hand carries it round; the line produced falls into itself, and forms an ellipse, of which the nails occupy the places called the foci. Those who have once tried the experiment, immediately perceive, that the longer the endless cord, while the nails retain the same distance, the nearer the ellipse approaches to a circle; and on the contrary, the shorter it is, the nearer the foci are to the sides. The distance between either of the foci and the centre of an ellipse, is called its eccentricity.

which the sun is situated, it is obvious that the distances of the planets from the sun is different at different times. The points of the greatest and least distance, when spoken of indifferently, are called the *apsides* of the planet; but when contradistinction is necessary, the point of greatest distance is called the *higher apsis*, or *aphelion;* the point of least distance is called the *lower apsis*, or *perihelion*. The line connecting these two points, is called the *line of the apsides*, and is supposed to pass through the centre of the sun.

When the sun or moon is at its least distance from the earth, it is said to be in *perigee*.—When either is at its greatest distance from the earth, it is said to be in *apogee*.

To those who live exactly under the equator, the poles of the world appear in the horizon; hence that situation is called the *right position of the sphere*.

To those who have either of the poles of the world in their zenith, the horizon coincides with, or is parallel to, the equator; hence that situation is called *a parallel sphere*.

To all the other inhabitants of the earth, the sphere is said to be in an *oblique position*, because the equator is neither perpendicular nor parallel, but oblique to the horizon.

These definitions and explanations are brought together, for the more easy reference of the reader; but a variety of others, with more enlarged explanations of some already enumerated, will be necessary as we proceed.

Of the apparent Motions of the heavenly Bodies.

As the true motions of the heavenly bodies can only be obtained by a careful observation of their apparent ones, it is absolutely necessary, for those who wish to become acquainted with them, to know perfectly the different changes which take place in the heavens as seen from the earth, the only place from which man can make any observation. By carefully attending to these, a little knowledge of optics will enable us to understand with great certainty, not only the true system of nature, but also what appearance the heavens would make to a spectator placed in any part of the visible creation.

When we cast our eyes towards the heavens, we perceive a vast concave hemisphere, at an unknown distance, and of which the eye seems to constitute the centre. The earth, or our sensible horizon, stretching on every side like an immense plain, appears to meet and to bound the heavenly expanse. The sun we observe to rise in the east, and to set in the west; after which the moon and stars appear, still keeping the same westerly course, till we lose sight of them altogether. We further discover, upon attentive and repeated observation, that neither

the sun nor the moon always rise exactly in the same point of the heavens. If we begin to observe the sun, for instance, in the beginning of March, we find that he seems to rise almost every day more to the northward than he did the day before, to continue longer above the horizon, and to be nearer the zenith at mid-day. This continues nearly to the end of June, when he is observed to move backward in the same manner; and his retrograde motion continues till nearly the end of December, after which he gradually attains the point from which he set out, and again renews the phenomenon.

The motion of the moon through the heavens, as well as her appearance at different times, are still more remarkable than those of the sun. When she first becomes visible, at the time she is called the new moon, she is in the western parts of the heavens, and appears to be at no great distance from the sun himself. Every night she not only appears larger but at a greater distance from the sun, till at last she rises from the eastern part of the horizon, just at the time the sun disappears in the western, and presents, at the same time, a completely circular face. She then gradually moves farther eastward, diminishing in size, and rising later and later every night, till at last she seems to approach the sun as nearly in the east as she did in the west, and rises only a little before him in the morning, as in the first part of her course she set in the west not long after him. All these different appearances are completed in the space of a month, after which they begin in the same order as before. They are not, however, at all times regular; for at some seasons of the year, particularly in harvest, the moon appears for several days to recede no farther from the sun, and to rise for several nights nearly at the same hour.

In contemplating the stars, on a clear evening, we observe continual changes. New stars keep rising in the east, while others are setting in the west. Looking towards the south, some stars just appear on the horizon, skim its boundary for a little while without rising above it, and then vanish; others, a little farther from the south, rise above the horizon, make a small arc, and then go down; while some again describe a large arc, and take a long time before they set. If we look toward the north, we find that some just skim the horizon, then mount to the middle of the heavens; then again descend and remount, without ever disappearing. Others describe complete circles, without descending to the horizon, and these circles diminish, till at last we arrive at a star that the eye cannot perceive to have any motion, but which seems to be in that particular point round which the whole hemisphere appears to turn. This star, is called the *pole-star*.

Upon considering these phenomena, it is easy to conceive, that as there is a hemisphere above us, there is also its counterpart below us, though invisible; and that, of course, the earth, with all its inhabitants, is suspended in the middle of this heavenly sphere, which the horizon divides into two parts. Consonantly with this idea, we find, that the remarkable star called the pole-star is more or less elevated, according to the different parts of the earth from which we take our view. The inhabitants of Lapland, for instance, see it much nearer the zenith that we do; we see it nearer the zenith than the inhabitants of France and Spain; and they again see it nearer the zenith than the inhabitants of Barbary. By continually travelling south, this star would be seen nearer and nearer to the horizon, and would at length become invisible. Another point would then appear in the south part of the horizon, round which the stars in that quarter would seem to turn. In the southern hemisphere, however, where we should now be arrived, there is no star so near the pole as in the northern, nor is the number of stars so great.

Hence we know that if the opacity of the earth did not limit our view, the general appearance of the heavens would be that of a vast concave sphere, turning round two points fixed in the north and south parts of it once in twenty-four hours.

On further observation of the stars, we find the greatest number of them to keep their places with respect to one another, that is, if we observe two stars having a certain apparent distance from each other this night, we find that they have the same to-morrow, and every succeeding night; but we by no means observe them to have the same places with respect to the sun and moon. The stars that do not appear to be of this fixed kind, are very few in number; the naked eye can see but seven, and astronomers, with the use of the best telescopes, have not added more than four to that number. These eleven stars are the planets and asteroids defined in the preceding section, and they change their places very remarkably with regard to the stars, and with regard to each other. Sometimes they seem to be moving to the westward, sometimes to the eastward, and sometimes they appear stationary for a considerable time. There are other bodies, which appear only occasionally, move for some time with prodigious velocity, and then recede from us so far, that they cease to be visible. These are comets, of which the number is unknown.

To obtain correct views of the motions of the heavenly bodies, it is necessary to possess the means of indicating with precision, the places they occupy. This is done by several imaginary lines or circles supposed to be described upon the

surface of the sphere. These circles are divided into degrees, minutes, and seconds: a degree, it has been already mentioned, is the 360th part of the circumference of a circle; a minute is the 60th part of a degree; and a second the 60th part of a minute. When these divisions are not expressed by words, degrees are marked by a small circle ° placed near the upper part of the figures; minutes by a small line ′ in the same situation, and seconds by two lines ″ of the like sort. This being premised, we shall first illustrate by a diagram, the position of the axis of the world, to which the imaginary circles of the sphere have a reference. Let HO, fig. 1, plate II, represent the circle of the horizon, seen edgeways, in which case it will appear as a straight line: let HMON represent the complete sphere of the heavens, of which, as only half of it can be seen at once, HMO may be considered the visible hemisphere, and HNO the invisible hemisphere: then P will be the pole or fixed point among the stars, visible to us, round which the sphere will appear to turn, and as the opposite point will be at R, the line PR will be the axis of the sphere.

If through the centre of the earth *c*, there be drawn a line QE, it will represent the edge of a great circle, which will be a quarter of a circle, or 90 degrees, distant from each pole. It is called the *equator*, because it divides the heavens into two equal parts, the north and south.

The equator having reference to the pole, is always the same, but this is not the case with the horizon, the position of which a spectator changes at every remove, consequently also the hemisphere he beholds, and the position of his zenith and nadir; these two points being always 90 degrees distant from his horizon. If HO be the horizon, M will be the zenith, and the opposite point N the nadir.

The horizon of a spectator can never be coincident with the equator, nor his zenith and nadir with the axis of the sphere, unless he be situated exactly at the pole. The zenith and nadir are often called the *poles of the horizon*; the young student must therefore be careful to distinguish these poles, which vary with the place of the spectator, from those of the world, which are constantly the same.

All circles drawn through the zenith and nadir, are perpendicular to the horizon, and are therefore called *vertical circles*, or *azimuths*.

Two of these *vertical circles* or *azimuths*, are particularly important, one of them is called the *meridian*, and passes through the poles, through the zenith and nadir, and cuts the equator perpendicularly. As this circle passes through the poles, it is obvious that if a spectator travels exactly north or south, he

may go round the globe without changing his meridian ; but if he travel east or west, he changes it every instant. The number of meridians may therefore be supposed to be infinite, but a very small number, seldom more than thirty-six, are drawn upon maps and globes. At mid-day, when the sun has attained his greatest elevation, his centre is precisely on the meridian of the place where he is observed, and the moment he has passed the meridian he declines towards the west. The meridian divides the circles described by the stars into two equal parts, and those stars which never sink below the horizon, may be observed to cross it twice in twenty-four hours. All the rest of the stars, as well as the sun, do the same, but when they pass the meridian below our horizon, they are of course invisible to us.

The second remarkable azimuth is called the *prime vertical.* It divides the eastern and western sides of the horizon into two equal parts, and the points of intersection are called the true east and west points; so that the meridian and prime vertical divide the horizon into four equal parts, and the points of division, viz. the *north*, the *east*, the *south*, and the *west*, are called the principal points of the horizon, or *cardinal points.*

These three great circles, viz. the equator, the meridian, and prime vertical, form the basis of reference in observations on the heavenly bodies, and it is therefore necessary to determine their relative situations. If the pole-star had been accurately at the pole of the heavens, nothing more would be necessary, in order to obtain the altitude of the pole, but to take the altitude of this star ; but as it is at the distance of 2 degrees from the pole, 2 degrees must be added to this altitude, to find that of the pole. The elevation of the pole being known, it is easy to find that of the equator. Thus, in fig. 1, pl. II, HMO, or the visible part of the heavens, contains 180 degrees ; and it is ninety degrees from the pole P, to E the equator. If, therefore, we take away PE from the semi-circle HMO, there remains 90 degrees for the other two arcs, PH, and EO, that is, the elevation of the pole and the equator are together equal to 90 degrees ; so that the one being known, and subtracted from 90, it will give the other. Hence the elevation of the pole, at any place, is equal to what the elevation of the equator wants of 90 degrees : and the elevation of the equator is equal to the distance from the pole P to the zenith M.

We cannot, under ordinary circumstances, observe the sun's motion among the fixed stars, because his splendour prevents their being seen; but we can observe the instant of his coming to the meridian, and his meridional altitude. We can also compute what point of the starry heavens comes to the same meridian at the same time, and with the same altitude. Or we can

observe that point in the heavens, which comes to the meridian at midnight, with a declination as far from the equator at one side, as the sun's is on the other side; and it is evident that the sun must be in that part of the heavens which is diametrically opposite to this point. By either of these methods, we obtain a series of points in the heavens, through which the sun passes in a year, and a line supposed to be drawn through them all, forms that circle called the *ecliptic*. This appellation is derived from the circumstance, that all the eclipses of the sun and moon are performed either actually in or very near it.

The ecliptic or annual path of the sun coincides with the equator only in two points; for the sun rises above the equator in summer, and does not rise so high in winter. Those two points of the ecliptic, where the sun is situated, when he is most distant from the equator, are called the *solstitial points*, and the points of intersection of the ecliptic and equator, are called the *equinoctial points*.

The *equinoctial colure* is the great circle which passes at right angles to the equator, through the equinoctial points. The *solstitial colure*, is another great circle cutting the equator at right angles, but passing through the solstitial points, and through the poles of the ecliptic.

The angle which the plane of the ecliptic makes with that of the equator, is called the *obliquity of the ecliptic*. The obliquity of the ecliptic is equal to the elevation of the sun above the equator when in either solstice. It amounts nearly to 23½°.

The smaller circles of the sphere are all those which have their centre in the axis, but not in the centre of the sphere; two of them cut the solstitial points, and their planes are at right angles to the axis of the world, as AC, BD, fig. 1, pl. II; these are called *tropics*, of which that on the south side of the equator is called the *tropic of Capricorn*, and that on the north side of the equator, the *tropic of Cancer*. The two *polar circles*, FG, IK, are at the same distance from the two poles that the tropics are from the equator, namely 23½°.

The distance of the heavenly bodies from the equator is called their *declination*, which is used with the addition of North or South, to denote on which side of the equator they are. The sun's declination can never exceed the obliquity of the ecliptic; but stars have all degrees of declination, because they have all degrees of altitude. Great circles, drawn through the poles of the equator, are called *circles of declination*, or *meridians*, because upon them declination is measured. Twenty-four of these circles of declination, are called *hour-circles;* because each contains 15 degrees, which space the sun passes over every hour.

The *right ascension* of the heavenly bodies is their distance

from the first point of Aries ♈, estimated in time on the equator, where cut by a declination circle passing through the body, reckoning, as above stated, 15 degrees for every hour.

The *oblique ascension* of a celestial body is an arc of the equator, extending, according to the order of the signs, from Aries to that point of the equator that rises with the star in an oblique sphere; and the difference between the right and the oblique ascension of the body, is called the *ascensional difference.*

The *latitude* of a star is its distance from the ecliptic, measured on a *circle of latitude,* which is a circle perpendicular to the ecliptic, and is either north or south, as the star is situated either on the north or south side of the ecliptic.

The *longitude* of a star is estimated from the first point of Aries to the place where a line from the star would cut the ecliptic perpendicularly, or would cut the star's circle of longitude. *Circles of longitude* are lesser circles parallel to the ecliptic, and which diminish as they recede from it. The longitude of a star, is of course, like its latitude, either north or south.

When the latitude or longitude of a celestial body is spoken of as if that body were seen from the centre of the sun, it is said to be *heliocentric;* but when the body is supposed to be seen from the earth, its latitude or longitude is said to be *geocentric.*

Of the Figure, Motion, and Magnitude of the Earth—Magnitude and Distance of the Sun and Moon—and of planetary Motion.

Having now taken a superficial view of the general phenomena of the heavens, and of the principal lines or circles which constitute the artificial means that have been adopted to give precision to our ideas in speaking of these phenomena;—we may now proceed to inquire whether the evidence of vision does not require correction from our judgment. This examination of our first impressions will lead us to ascertain, if we can, the real figure and size of the earth; and when we have satisfied ourselves on these points, we may then proceed to consider whether the earth is in motion or at rest, for till we have done this, it is clear we can form no rational judgment of the real motions of the stars.

Mankind at first considered the earth to be an illimitable plain, and we have every reason to suppose, that they found it difficult to divest themselves of a prejudice so natural. But when observations of certain appearances on the earth, and of the motions of the heavenly bodies, became considerably multiplied, and compared with each other, the more penetrating of our

forefathers would perceive that the earth could not possibly be a plain, and that if it was not a plain, it was in all probability not boundless. In the flat countries of the East, on approaching any elevated and very distant object, it would be perceived that the top of that object first became visible, that the lower parts appeared in regular succession, and that the base was seen the last of all. This would be found a constant phenomenon, depending upon no accidental circumstance, but observable in every direction; and the clearer the atmosphere, and the more distinct the difference between the base and the summit, the more obvious it would appear. If the earth were a plain, the surface of water might certainly be expected to exhibit perfect flatness; the local inequalities of the land were easily accounted for, but water could rest only at a perfect level. When, therefore, in sailing from land, it was found that the base of all elevated objects disappeared first, and all the other parts in succession, in a still more regular and remarkable manner than upon land, a doubt could hardly remain of the curvature of the earth's general surface; the progress of knowledge gradually rendered the fact more evident, and at last it received the most ample confirmation, from a circumstance within the comprehension of every one. Magellan, Sir Francis Drake, Lord Anson, Captain Cooke, and others, have all, at different times, sailed round the earth. They set out from European ports, and by steering their course westward, arrived at length at the very place they departed from; which could not have happened, had the earth been of any other than a globular figure. These, as well as all other navigators and travellers, whatever the direction or length of their course, still find themselves surrounded, as much as those who never change their residence, by the same appearance of an immense vault, in which the stars are beheld. It is clear, therefore, that the earth has nothing analogous to what men would call a support, but that it exists by itself, perfectly detached from all other bodies, "in the unfathomable expanse of the Universe."

From the spherical form of the earth, it follows, that all its inhabitants, being directed, with their feet towards the centre of it, must be variously inclined to one another, in a manner easily represented by drawing lines from the circumference of a circle so as to point to its centre, or still better by sticking pins into a ball in the same direction. The inhabitants of countries diametrically opposite, are called the *antipodes* of each other.

To the mind just entering the confines of philosophy, it seems a strange and inconceivable thing, that people can stand on every side of a globe, and that there can be those who have their

feet opposite to ours; but when they have considered a little the nature of the attraction of gravitation, for the general doctrine of which we must refer to the pages we have devoted to the subject, they will soon perceive that the greatest absurdity would be to suppose the contrary. They will perceive also, that the terms up and down, with respect to the universe, have no absolute or constant meaning; for the region which we call uppermost, is opposite the feet of our antipodes; and the region opposite our feet, is consequently above their heads. But with respect to the earth, the words up or down, above or below, mean the situations nearer to, or farther from its centre, to which all bodies on its surface are unceasingly drawn, in a right line, by the influence of gravitation.

When the globular form of the earth became clearly understood, a tolerable idea of its size could not be long a secret. We have the record of the attempt to measure it being made 550 years before the Christian era; but the first time that great accuracy was shewn, was in 1635, by Richard Norwood, who measured the distance between London and York with a chain; then having ascertained the sun's meridian altitude, for the same moment, at each extremity of this known base, he deduced that a degree, or the 360th part of the earth's circumference, amounted to 69½ miles, and 14 poles, from which he found that the circuit of the earth was about 25,036 miles.

When the size of the earth was supposed to be known, the next object of astronomical investigation might very properly be, to discover the size and distance of the sun, moon, and stars. To offer conjectures respecting these bodies, before something like adequate ideas of their distances were obtained, would be folly; and to do it before the figure and size of the earth were demonstrated, could not lead to any satisfactory conclusions.

When the effects of the sun, in giving light and heat, were compared with the effects of any artificial fire, it would be admitted by the most ignorant, that the size of that luminary must be very great; but the ideas of the earliest ages, on such a subject, could never be commensurate to the truth. We must, however, leave the speculations of the ancients, with observing, that every method which ingenuity could devise, has been tried, to resolve the interesting questions of the sun and and moon's distances in particular; but the only one which can satisfy the mind, is that which depends upon mathematical principles, and which is similar to that employed in the measurement of distant terrestrial objects. From the two extremities of a base, whose length is known, the angles which the visual rays from the object, whose distance is to be measured,

make with the base, are measured by means of a quadrant; their sum, subtracted from 180°, gives the angle which these rays form at the object where they intersect. This angle is called the parallax, and when it is once known, mathematicians find it easy, by means of trigonometry, to ascertain the distance of the object. Let AB, in fig. 2, pl. II, be the given base, and C the object whose distance we wish to ascertain. The angles CAB and CBA,* formed by the rays CA and CB with the base, may be ascertained by observation; and their sum, subtracted from 180°, leaves the angle ACB, which is the parallax of the object C. It gives us the apparent size of the base AB, as seen from C. When this method is applied to the heavenly bodies, it is necessary to have the largest possible base, and in the usual astronomical sense, the parallax of a star is the difference between its true and apparent distance from the zenith. In explanation of this subject we may observe, that when a star is in the zenith, it is seen by the spectator on the earth's surface, where it would appear if it could be seen from the earth's centre; it is therefore seen in what is called its true place; but when the star is not in the zenith, a spectator does not see it in the same place that he would, could he view it from the centre of the earth; but, in all cases, the difference between the true and apparent place of an object is less in proportion as its distance is greater. Of the popular illustrations of the method of taking a parallax, the following by Walker is perhaps one of the plainest: Suppose the distance of the moon were our first object, and that we had a sea horizon, and were situated so that the moon passed over our zenith; then let A, fig. 3, pl. II, be the earth, and *a* the place of the observer, who must be supposed to have a quadrant, *b c*, by which he can note the moment the moon comes to the zenith. Now as the moon apparently passes from a meridian to that meridian again in twenty-four hours and forty-eight minutes, she will perform a quarter of that circuit, viz. from *d* to *e*, in a quarter of that time, or in six hours and twelve minutes. But the observer will find that she will set before the six hours and twelve minutes are expired, which he must note; for when she comes to his sensible horizon, *a c g*, she sets to him. Now as the sensible horizon is parallel to the rational horizon *k e*, a diagonal *a e*, will make the angle *c z* equal to *n*, its opposite angle. To find what the angle *c z* is, say, by the rule of three, if six hours and 12 minutes be required for a quarter of the moon's circuit, or 90°, viz. from

* When an angle is referred to, the middle letter indicates its vertex, or the centre of the circle upon which it is measured.

d to *e;* how many degrees of the ninety would she pass through in the time of her going from the zenith to the sensible horizon, or from *d* to *g*, which being taken from 90°, or the quadrant *d e*, will leave the quantity of the arch *g e*, or the angle *c z*. Now as the angle *n* is equal to *c z*, we are in possession of a right-angled triangle *a k e*, with a side and an angle known; for *a k*, the semi-diameter of our globe, is nearly 3960 miles: it is the property of a right-angled triangle to have its sides proportional to the sides of its opposite angles; therefore as the angle *n* is to its opposite side *a k*, so is the angle *o* to its opposite side *k e*, or the mean distance of the earth's centre from that of the moon, viz. 240,000 miles. The parallax or angle *n*, is on a medium about 57″.

The sun is so distant, that his parallax or angle *g a* S is too small to be measured with any certainty by a horizontal parallax. The radius of the earth is indeed found to be an almost insignificant space compared with the sun's distance. Dr. Halley therefore recommended the transits of Venus, which were to happen in the years 1761 and 1769, as affording the best means of ascertaining the distance of the sun. The transit of a planet takes place when the planet comes exactly between the earth and the sun, whose disc it traverses in the form of a small round, dark spot. Transits can only be exhibited by the planets Mercury and Venus, because no other have their orbits within that of the earth. Only two transits of Venus occurred during the last century, and there will not be another till 1874. By these transits, which were very carefully observed, almost the whole diameter of the earth formed a parallax, instead of the above semi-diameter, by which a commensurate angle was thus procured: Venus moves in her orbit in the direction *z n*, fig. 4. pl. II, and from the centre of the earth *c*, would be seen to move over the sun's disc from *s* to *v;* an observer therefore at *a*, would see the contact at *s*, at the same instant that one at *b* would see the planet at *u;* and one at *d* would see it at its egress at *v*, along the line *d* V *v*. This would be the case were the earth at rest; but it is turning on its axis in the direction *a b d*. Now if the planet stood still at V, while the earth turned from *a* to *d*, that time would be easily turned into the parallactic angle *a* V *d*, and might be treated like that of the moon; but the motion of Venus, as well as that of the earth, was to be taken into this calculation, as well as observations made in different latitudes; after taking every possible precaution, and making every requisite allowance, the sun's parallax was found to be about 8″; the angle, though so very small, admits of calculation, and the sun's distance was from it deduced to be about 96 millions of miles.

The distances of the sun and moon being thus determined, the facility of ascertaining their size is comparatively great; because it may be approximated by very easy calculations, according to the principles of optics. The angle subtended at the eye by an object is easily measured, and is inversely as the distance of that object. Now the distance gives the radius of a circle, the centre of which is at the pupil of the spectator's eye, and on the circumference of which is the object, which we will suppose to be the sun. Having the radius, the circumference of this immense circle is obtained by the common arithmetical method; and when we have the circumference, the value or extent of its degrees and minutes may also be found. Therefore, if the number of minutes subtended by the sun, be multiplied by the value of a minute, we have the diameter of that luminary. In ascertaining the distances as well as the magnitudes of the sun and moon, a variety of mathematical and mechanical means are resorted to, in order to secure the most accurate results; but it would be useless on the present occasion to enter upon the consideration of the details. It is enough to give, with their results, a general idea of the processes employed, and to observe, that by the latest and most careful calculations, the moon has been found to be 2180 miles in diameter; and the diameter of the sun 883,246 miles. The evidence in favour of these dimensions being very nearly correct, is so conclusive, as to enforce conviction in every mind open to the investigation of truth.

When the sphericity of the earth, its insulated existence, and its magnitude, have become familiar to the young student; and, keeping in mind the general doctrine of attraction above referred to, when he has further compared these three circumstances with the correspondent circumstances of the sun and moon, he will then perhaps begin to inquire, whether the real motions of the sun and moon are such as they appear to be, and whether the earth revolves round them, or they round the earth. With respect to the moon, a very momentary attention will give satisfaction. This satellite always presents to us the same face or side; therefore she revolves round the earth, otherwise this would be impossible. But with respect to the sun, in thus consulting his judgment, he will have much reason for doubt, and to believe that the evidence of sense is fallacious. The sun is a million of times larger than the earth, and if he revolves round the earth in twenty-four hours, he must each hour advance over a space of more than 24,000,000 of miles. That a body of such prodigious size should revolve at such a rate round another body, which (like the earth to the sun) is a mere point when compared

with it, is as absurd as to suppose that a grain of sand should command the motion of a mill-stone, or a pepper-corn that of a mountain. It would be totally irreconcileable with all that we know of the simplicity of the laws of nature, which always accomplish the grandest objects by the simplest means; and when we advanced to the consideration of other celestial phenomena, we should find our difficulties increase with our progress, till at last inextricable confusion beset us. It is absolutely necessaryto relinquish the idea that the earth is immoveable, and philosophers, after the most minute investigation of the phenomena, have completely shewn, that the earth has at least two motions, one on its own axis, called its diurnal motion, which causes it to revolve from east to west in twenty-four hours, and the other a progressive motion, called its annual motion, which carries it round the sun once in a year. The diurnal motion produces the regular return of day and night, and the apparent revolution of the sphere; the annual motion produces the vicissitudes of the seasons, summer, winter, spring, and autumn.

It is no reason against the rotation of the earth, tnat we are unable to perceive it. For as the motion of a ship at sea, when swiftly sailing over the smooth surface of the water, is not perceptible to the company on board; certainly we may expect that so large a body as the earth, which has no impediment in its way, or resistance to overcome, will in this respect deceive us effectually. It has been asserted again, that if the earth moved, a stone dropped from the top of a tower, or any other high building, would not fall just at the bottom of it, as the building must have advanced considerably forward, during the time of the fall. But this is evidently a mistake; for it is well known, by repeated experiments, that if a body be projected from another body in motion, it will always partake of the motion of that other body. Thus, a stone dropped from the top of a mast, while the ship is under sail, is not left by the vessel, but falls exactly at the foot of the mast. And if a bottle of water be hung up in the cabin; with its neck downwards, it will empty itself, drop by drop, into another vessel placed exactly underneath it, though the ship shall have run many feet whilst each drop was in the air.

The motion of the earth, in the manner stated by astronomers, being admitted, as also the magnitudes and distances of the sun and moon, the remaining wonders of astronomy, though they may overwhelm with the idea of immensity, will scarcely excite disbelief. It is found by data as indisputable as those which establish the facts hithert mentioned, that

the planets or wandering stars, and the comets, all revolve round the sun in different orbits, and that these bodies are in reality all of them worlds. We shall therefore make a few remarks on that power which preserves them in the order we observe, and afterwards proceed to the separate consideration of them as parts of the solar system.

When Sir Isaac Newton undertook the reformation of philosophy, he proceeded upon a very different plan to those who had gone before him; he proposed to assume nothing as an hypothesis which was not deduced from data acknowledged and obvious to our eyes, and thus, by arguing from those things which are within our reach, he thought we might come to know with certainty what must happen in the celestial regions. The manner in which he was first led to form his system of gravitation, which is now universally received, is said to have been as follows: He was sitting alone in a garden, when some apples falling from a tree, directed his thoughts to the subject of gravity, or the cause of their fall; and reflecting on that principle, he began to consider, that, as its power is not found to be sensibly diminished at the most remote distance from the centre of the earth to which we can rise, neither at the tops of the loftiest buildings, nor on the summits of the highest mountains, it was reasonable to conclude that its influence must extend much further than was usually thought. Then a train of thought arose in his mind, "Might it not extend as far as the moon; and if so, must not her motion be influenced by it? perhaps it retains her in her orbit: however, though the power of gravity is not sensibly weakened in the little change of distance, at which we can place ourselves from the centre of the earth, yet it is very possible, that, as high as the moon, this power may differ much in strength from what it is here." To make an estimate of the degree of this diminution, he considered, that if the moon be retained in her orbit by the force of gravity, no doubt the primary planets were retained in their orbits by a similar gravitation towards the sun; and by comparing the periods of the several planets with their distances from the sun, he found, that if any power like gravity held them in their courses, its strength must decrease in the duplicate proportion of the increase of distance. This was concluded from a supposition that these bodies moved in perfect circles round the sun; which, though they are not found to do exactly, yet the error was but of little consequence.

To account then for the perpetual motions of the planets and comets in their orbits, Newton had recourse to the force of gravity, and a projectile force compounded with it. These two

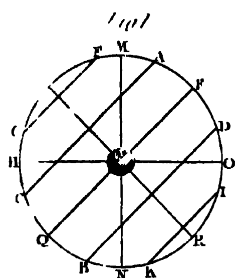
forces had indeed been proposed by Horrox, before his time, with the same view; and the power of gravity, as existing in the celestial regions, had been intimated by several philosophers; but their ideas appeared as little better than vague speculations, and were almost unnoticed by the world. As Newton was ignorant of any natural power by which the planets could be impelled in the direction of a tangent line to any part of their orbits, he had recourse, for one of the forces, to the immediate action of the Deity. According to him, God having created this world, impressed the universal law of attraction or gravitation upon matter, and impelled each of the planets in the direction of a right line touching their orbits. Being immediately acted upon by the attraction of the sun, their courses were bent from a straight line into a curve; and the same causes still continuing to act, the original rectilinear direction was changed into one nearly circular, which has continued ever since. The same mode of reasoning is applicable to the continued motion of the secondary planets round their primaries. The manner in which Sir Isaac Newton demonstrates the operation of the projectile and gravitating forces upon the planets, so as to direct them in circles round the sun, is by supposing the orbits they describe divided into infinitely small parts, each of which will not differ from a right line, and consequently the whole curve may be considered as consisting of the diagonals of parallelograms infinitely small, one of whose sides is represented by the space which the planet would have moved through by the projectile force alone, and the other by that which it would have moved through by the force of gravity alone, in the same time. To those who would enter deeply into the subject, Newton's Principia will afford ample gratification, but it will better suit our purpose of popular illustration to adopt the following explanation of Ferguson:

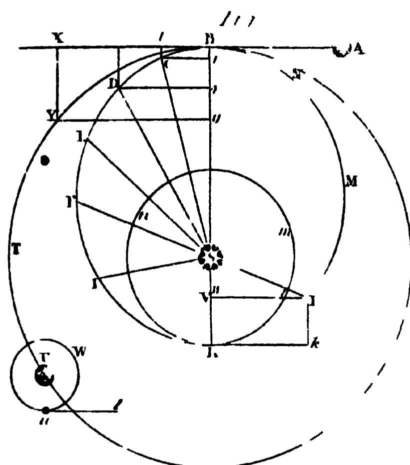
"From the uniform projectile motion of bodies in straight lines, and the universal power of attraction which draws them off from these lines, the curvilineal motions of all the planets arise. If the body A be projected along the right line ABX, fig. 5, pl. II, in open space, where it meets with no resistance, and is not drawn aside by any other power, it will for ever go on with the same velocity and in the same direction. For the force which moves it from A to B in any given time, will carry it from B to X in as much more time, and so on; there being nothing to obstruct or alter its motion. But if, when this projectile force has carried it, suppose to B, the body S begins to attract it, with a power duly adjusted, and perpendicular to its motion at B, it will then be drawn from the straight line ABX, and forced to revolve about S in

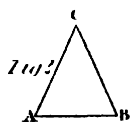
the circle BYTU. When the body A comes to U, or any other part of its orbit, if the small body *u*, within the sphere of U's attraction, be projected as in the right line Z, with a force perpendicular to the attraction of U, then *u* will go round U in the orbit W, and accompany it in its whole course round the body S. Here, S may represent the sun, U the earth, and *u* the moon.

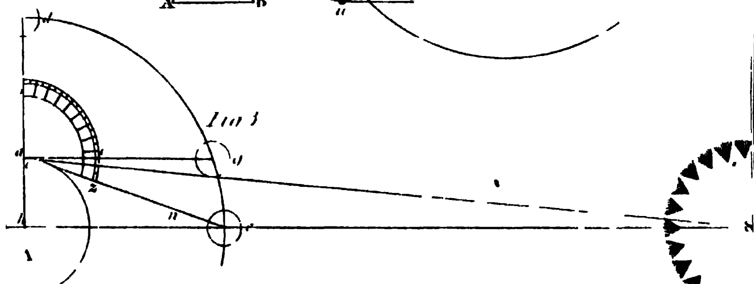
"If a planet at B gravitates, or is attracted towards the sun, so as to fall from B to *y*, in the time that the projectile force would have carried it from B to X, it will describe the curve BY, by the combined action of these two forces, in the same time that the projectile force singly would have carried it from B to X, or the gravitating power singly have caused it to descend from B to *y*; and these two forces being duly proportioned and perpendicular to each other, the planet obeying them both, will move in the circle BYTU. To make the projectile force balance the gravitating power so exactly, as that the body may move in a circle, the projectile velocity of the body must be such as it would have acquired by gravity alone in falling through half the radius of the circle.

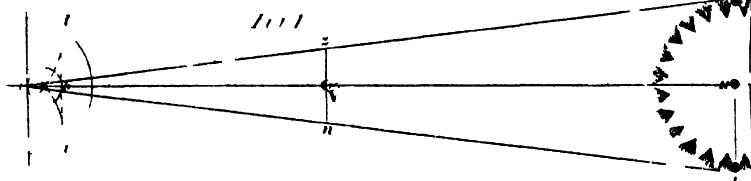
"But if, whilst the projectile force would carry the planet from B to *b*, the sun's attraction (which constitutes the planet's gravitation) should bring it down from B to 1, the gravitating power would then be too strong for the projectile force, and would cause the planet to describe the curve BC. When the planet comes to C, the gravitating power (which always increases as the square of the distance from the sun, S, diminishes) will be yet stronger for the projectile force, and by conspiring in some degree therewith, will accelerate the planet's motion all the way from C to K; causing it to describe the arcs BC, CD, DE, EF, &c. all in equal times. Having its motion thus accelerated, it thereby gains so much centrifugal force, or tendency to fly off at K, in the line K *k*, as overcomes the sun's attraction; and the centrifugal force being too great to allow the planet to be brought nearer the sun, or even to move round him in the circle K *l m n*, it goes off, and ascends in the curve KL MN, &c. its motion decreasing gradually from K to B, as it increased from B to K, because the sun's attraction now acts against the planet's projectile motion just as much as it acted with it before. When the planet has got round to B, its projectile force is as much diminished from its mean state about F or M, as it was augmented at K; and so the sun's attraction being more than sufficient to keep the planet from going off at B, it describes the same orbit over again, by virtue of the same forces or powers.

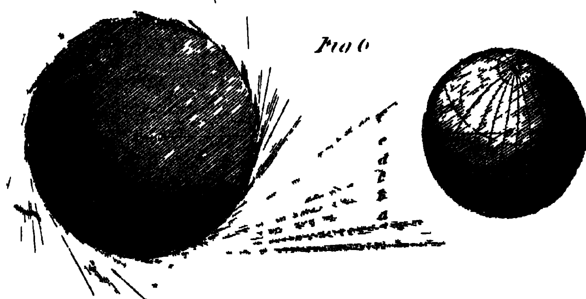

Fig. 1
F
M
A
E
C
D
H
O
G
I
Q
R
B
N
K


X
B
A
D
Y
L
M
T
S
V
I
k
W
T


C
A
B


Fig. 3


Fig. 4


Fig. 6
e
d

Explanation of planetary motion.

"A double projectile force will always balance a quadruple power of gravity. Let the planet at B have twice as great an impulse from thence towards X, as it had before; that is, in the same length of time that it was projected from B to *b*, as in the last example, let it now be projected from B to *c*; and it will require four times as much gravity to retain it in its orbit: that is, it must fall as far as from B to 4, in the time that the projectile force would carry it from B to *c*; otherwise it would not describe the curve BD, as is evident by the figure. But in as much time as the planet moves from B to C, in the higher part of its orbit, it moves from I to K, or from K to L, in the lower part thereof; because, from the joint action of these two forces, it must always describe equal areas in equal times throughout its annual course. These areas are represented by the triangles BSC, CSD, DSE, ESF, &c. whose contents are equal to one another quite round the figure.

"As the planets approach nearer the sun, and recede farther from him, in every revolution; there may be some difficulty in conceiving the reason why the power of gravity, when it once gets the better of the projectile force, does not bring the planets nearer and nearer the sun in every revolution, till they fall upon and unite with him; or why the projectile force, when it once gets the better of gravity, does not carry the planets farther and farther from the sun, till it removes them quite out of the sphere of his attraction, and causes them to go on in straight lines for ever afterward. But by considering the effects of these powers, as already described, this difficulty will be removed. Suppose a planet at B to be carried by the projectile force as far as from B to *b*, in the time that gravity would have brought it down from B to 1: by these two forces it will describe the curve BC. When the planet comes down to K, it will be but half as far from the sun, S, as it was at B; and therefore, by gravitating four times as strongly towards him, it would fall from K to V in the same length of time that it would have fallen from B to 1 in the higher part of its orbit, that is, through four times as much space; but its projectile force is then so much increased at K, as would carry it from K to *k* in the same time, being double of what it was at B; and is therefore too strong for the gravitating power, either to draw the planet to the sun, or cause it to go round in the circle K *l m n*, which would require its falling from K to *w*, through a greater space than gravity can draw it, while the projectile force is such as would carry it from K to *k*; and therefore the planet ascends in its orbit KLMN, decreasing in its velocity, for the causes already assigned.

"By the above-mentioned law, bodies will move in all kinds

of ellipses, whether long or short, if the spaces they move in be void of resistance. Only, those which move in the longer ellipses, have so much the less projectile force impressed upon them in the higher parts of their orbits; and their velocities, in coming down towards the sun, are so prodigiously increased by his attraction, that their centrifugal forces, in the lower parts of their orbits, are so great as to overcome the sun's attraction there, and cause them to ascend again towards the higher parts of their orbits; during which time the sun's attraction acting so contrary to the motion of those bodies, causes them to move slower and slower, until the projectile forces are diminished almost to nothing; and then they are brought back again by the sun's attraction, as before."

The celebrated Kepler discovered, by assiduous observation, the two remarkable laws of planetary motion; and in honour of him they are called Kepler's laws. Sir Isaac Newton demonstrated them according to the above theory of attraction, and they shew, in a remarkable manner, the harmony of the celestial motions:

I. If a straight line be drawn from a planet to the sun, and this line be supposed to be carried along by the periodical motion of the planet, then the areas which are described by this right line and the path of the planet, are proportional to the times of the planet's motion; for instance, the area thus described in two hours, is the double of that which is described in one hour, and a third part of that which is described in six hours; though the arc which is described by the planet itself in two hours, is not the double of the arc which is described by the same in one hour; nor the third part of that which is described in six hours.

II. The planets are at different distances from the sun, and perform their periodical revolutions in different times; but the cubes of their distances, or of the principal axes of their elliptical orbits, are constantly as the squares of their periodical simes, viz. of the times of their performing their periodical revolutions.

The sun forms the centre of attraction, round which all the planets move; but all the planets and comets, according to the quantities of matter they contain, and their distance, exert their power of attraction upon the sun. The sun, therefore, is not at rest; but as his magnitude so greatly exceeds that of all the planets and comets put together, and as these exert their attractive powers in opposite directions, from being on opposite sides, the centre of gravity of the whole system, which is the point round which the sun performs a circuit, is always

near him, and generally within his body. From the grand principle of universal attraction, also, it follows that the planets must attract each other; and in fact it has not escaped the observation of philosophers, that they sensibly disturb each other's motions. When any two planets are in conjunction, their mutual attractions, which tend to bring them nearer to one another, draws the inferior one a little farther from the sun, and the superior one a little nearer to him; by which means the figure of their orbits is somewhat altered, though the alteration is too small to be discovered in several ages.

The orbits of such planets as have one or more moons, are still more remarkably disfigured by the attraction of these attendants; for example, the point which describes the orbit of the earth round the sun, is not the centre of the earth, but the common centre of gravity of the earth and moon, and which is found by calculation, on comparing their quantities of matter, to be about 2000 miles from the earth's surface. But these irregularities, while they shew the truth of the theory that accounts for them all, are too inconsequential to require much notice in a popular view of the solar system.

Of the Solar System.

The plate, marked Solar System, is intended to give an idea of the appearance of that system, could a spectator view it from a considerable distance above the sun, in a line perpendicular to the earth's orbit. In every plan of this kind, however, some sacrifices of strict propriety are made for the sake of convenience. The sun is only supposed to be seen by the radiance he throws around; the planets and their satellites, with their distances from the centre of the sun, are not exhibited in due proportion; and the orbits of all the planets are represented by circles, from which the reader will recollect they differ so little, that though in reality ellipses, they could scarcely on so small a scale be distinguished from circles. Of the comets, but four are noticed, each moving in an orbit of different eccentricity; but the actual number of these bodies is known to be very considerable, though by no means determined.

To a spectator, situated where we have supposed, above the sun, the planetary motions would appear extremely regular; but it is easy to conceive, that to one situated sideways, or viewing them, for example, as from the earth, they will exhibit great anomalies. Accordingly, the planets sometimes appear to be going forwards, sometimes backwards, and sometimes appear to be stationary. These irregularities are such as

must take place, if the Copernican be the true system of nature, and therefore the observation of them is a proof of the correctness of that system.

The planetary bodies of the Solar System, so far as at present known, and commencing with the one nearest the sun, are the following:

1. Mercury,
2. Venus,
3. The Earth, with one Satellite or Moon,
4. Mars,
5. Vesta,
6. Juno,
7. Ceres,
8. Pallas,
9. Jupiter, with four Satellites,
10. Saturn, with seven Satellites,
11. Herschel, with six Satellites.

The fifth, the sixth, the seventh, and eighth, are the four which Dr. Herschel calls asteroids. After treating of the sun, we shall notice all the planetary bodies in their order.

The Sun, ☉

The sun is an immense globe, the mean diameter of which amounts to 883,246 miles. When viewed through a telescope, dark spots, of various sizes and duration, are perceived on its surface; and from observations on the motions of these spots, it has been found that the sun revolves on its axis, from east to west, once in 25 days, 14 hours, 8 minutes, and his axis deviates about 8° from a perpendicular to the plane of the ecliptic.

The dark spots of the sun's surface, are often called *maculæ;* and those parts which are brighter than the rest, are called *faculæ.*

A variety of very different and heterogeneous conjectures have been offered to account for the maculæ. As the constant emanation of light and heat, induced the opinion that the sun was nothing else than one prodigious mass of fire, so it was interwoven with the idea that so vast a combustion required adequate accessions of matter to keep it up; on this account, it was supposed that the maculæ might be only the scoria, or unconsumed portions of the additional fuel, swimming on the liquid surface of the sun. Faculæ, on the contrary, have been called clouds of light, and luminous vapours; and because maculæ have sometimes been observed to change into faculæ, it has been conjectured, that the latter were the dark fumes of

volcanoes rapidly blazing out, after the dark smoky matter, which produced the maculæ, became dissipated by combustion. But these ideas partook very much of the vagaries of imagination; they possessed nothing admirable in themselves, and no attempt was made to render them, in a satisfactory manner, consistent with all the phenomena. In the year 1788, however, appeared a dissertation by Edward King, F. R. S. which contained many original remarks: this philosopher asserted, that the real body of the sun is less than its apparent diameter; that we never discover the real body of the sun itself, except when we behold its spots, (maculæ,) that the sun is inhabited as well as our earth, and is not necessarily subject to burning heat; and that there is in reality no violent elementary heat existing in the rays of the sun themselves essentially.

Several years after the publication of these opinions by King, Dr. Herschel began to publish, in the Philosophical Transactions, his theory concerning the nature of the sun, and to which he was led by his numerous observations, made with his admirable instruments, and the most persevering industry. This theory has received a degree of acceptance proportionate to the skill with which it was established, and we subjoin the following outline of it:

The Doctor considers the sun to be a magnificent habitable globe, surrounded by a double set of clouds. Those which are nearest its opaque body, are less bright and more closely connected together than those of the upper stratum, which form the luminous apparent globe we behold. This luminous external matter, he observes, is neither a liquid nor an elastic fluid of an atmospheric nature; for in either of these two cases, it would not admit of any chasms or openings. Therefore, it must be concluded that this shining matter exists it the manner of empyreal, luminous, or phosphoric clouds, residing in the higher regions of the solar atmosphere. The Doctor then is of opinion that the spots are only accidental openings between the luminous clouds, through which we behold the opaque body of the sun, or the inferior less luminous clouds; hence the spots appear of different shades. The Doctor rejects the terms maculæ, faculæ, luculi, and others previously in use, and substitutes the following, as better adapted to express what he considers the true phenomena of the sun.

Openings are those places where, by the accidental removal of the luminous clouds of the sun, its own solid body may be seen; and this not being lucid, the openings through which we see it may, by a common telescope, be mistaken for mere black spots or their nuclei.

Shallows are extensive and level depressions of the luminous solar clouds, generally surrounding the openings to a considerable distance. As they are less luminous than the rest of the sun, they seem to have some distant, though very imperfect, resemblance to penumbræ; which might occasion their having been called so formerly.

Ridges are bright elevations of luminous matter extended in rows of an irregular arrangment.

Nodules are also bright elevations of luminous matter, but confined to a small space. These nodules and ridges correspond to what have hitherto been called faculæ and luculi.

Corrugations, he applies to that very particular and remarkable unevenness, ruggedness, or asperity, which is peculiar to the luminous solar clouds, and extends all over the surface of the globe of the sun. As the depressed parts of the corrugations are less luminous than the elevated ones, the disc of the sun has an appearance which may be called mottled.

Indentations are the depressed or low parts of the corrugations; they also extend over the whole surface of the luminous solar clouds.

Pores are very small holes or openings, about the middle of the indentations.

As the Doctor considers the solar clouds to consist rather of a flame than a liquid substance, he attributes the spots to the emission of an aëriform fluid, not yet in combustion, which displaces the general luminous atmosphere, and which is afterwards to serve as fuel for supporting the process; hence he supposes the appearance of copious spots to be indicative of the approach of warm seasons on the surface of the earth, a theory which he has attempted to maintain by historical evidence. The shallows he considers as parts of an inferior stratum of opaque clouds, capable of protecting the immediate surface of the sun from the excessive heat produced by combustion in the superior stratum, and probably of rendering this stupendous world fit for animated existence. In general, more or less of the real body of the sun is supposed to be visible through its lucid atmosphere, where the substance is not very intense, or where it is removed by the varying circumstances of the combustion. As some of the spots appear below the surface of the shining fluid, it may be presumed that they shew us the lower parts of the sun's surface; and as other spots appear above the shining fluid, it is equally reasonable to conclude, that they are the solar mountains. The former kind of spots are very variable in situation, and it is clear, that if we have the true theory of the sun before us,

they may never occur twice precisely at the same place The spots attributed to the projection of the solar mountains are fixed with respect to the sun's surface, and are those by which the sun's rotation on his axis has been determined. Dr. Herschel, taking into consideration the great attraction exerted by the sun upon bodies placed at its surface, and the slow revolution it has about its axis, thinks that the solar mountains may be more than 300 miles high, and yet stand very firmly.

Dr. Young, in opposition to the theory of Dr. Herschel, argues, that if we inquire into the intensity of the heat which must necessarily exist wherever this combustion is performed, we shall soon be convinced that no clouds, however dense, could impede its rapid transmission to the parts below. Besides, the diameter of the sun is 111 times as great as that of the earth; and at its surface, a heavy body would fall through no less than 450 feet in a single second; so that if every other circumstance permitted human beings to reside on it, their own weight would present an insuperable difficulty, since it would become thirty times as great as upon the surface of the earth, and a man of moderate size would weigh above two tons. This hypothesis is not so satisfactory as Dr. Herschel's. If the sun be not inhabited, the only adequate purpose of its existence which we can conceive, is that of maintaining the existence of the other parts of the solar system; and that this is the only or chief use of it, is inconsistent with that frugality of means which appears the more eminent, the more closely we examine the works of nature. As the sun is so much larger than the aggregate mass of the planets, if it had been endued with no more inherent heat than we can easily reconcile to our gross ideas of organization, it would have supported a greater number of inhabitants than all the planets, supposing each of them to be the residence of living beings. It seems absurd, then, to suppose that the sun is created solely for the use of the comparatively mean and diminutive worlds that surround him; and a strange, unphilosophical limitation of the Deity's power and beneficence, to conclude that he cannot call into existence beings whose organs are as admirably suited to their peculiar circumstances on the sun, as we are to our own situation. With the knowledge we possess of modes of existence infinitely diversified, we cannot deny the existence of the power to produce such beings; and when we consider the fulness of creation within the sphere of our observation, it seems as difficult to deny the presence of the will to create them, rather than leave a mighty blank of that possible happiness, which myriads of beings might enjoy. The arguments against

the inhabitable condition of the sun, drawn from the circumstance of the excessive weight of bodies on its surface, are inconclusive, unless inhabitants could be formed only of the same kind of matter as ourselves; which is not certainly the most probable conjecture. It may also be observed, that the strength or muscular energy of ordinary men is not more inferior to the muscular energy of some individuals that have occasionally appeared in the world, than the muscular energy of these remarkable men is inferior to what an inhabitant of the sun would require, provided greater muscular energy were the only means he possessed to overcome the disadvantage of his weight.

With respect to the excessive heat at the surface of the sun, there are many facts which shew that heat is produced by the sun's rays only when they act on a calorific medium; they produce heat by uniting with the matter of fire which is contained in the substances that are heated. The collision of a flint and steel will inflame a magazine of gunpowder, by putting all the latent fire which it contains into action; while the same spark upon a heap of sand would not have the slightest effect. Now if we suppose the matter on the surface of the sun, not to admit of any extensive chemical combination with its rays, it is easy to perceive, that the heat may not be such as to be inconsistent with organized existence.

Walker's speculations on the sun are very ingenious. He supposes the particles of light, which constitute the solar atmosphere, strongly to repel each other; that this property of repulsion is one cause of the light being dispersed or projected in every direction through space; but that, at the equatorial regions of the sun, the centrifugal force created by his rotation, co-operating with repulsion, produces a more copious emission of the vital ocean, than at the polar regions. The sun turns on an axis inclined but 8° from the plane of the ecliptic; his equatorial, or greatest centrifugal discharge of particles, will therefore be nearly confined to the zodiac or track of the planets, where the greatest supply is required. Taking for granted, (and we shall afterwards see the reasonableness of the belief,) that the fixed stars are suns, he supposes that these suns recruit each other, by imbibing, at and near their poles, most of the light that reaches them; for towards their poles, the strong attraction of the sun's body overcomes the repulsion of light, when that repulsion is but little assisted by the centrifugal force; and the light thus imbibed, sinks down for the supply of the equatorial regions. But a still more beautiful part of this hypothesis, is, that it explains the cause of the diurnal motion of the earth and other planets, which Newton left unaccounted for

Light has been shewn (see Optics) to possess momentum; suppose then, S, fig. 6, plate II, to be the sun, and E the earth, and that the lines *a, b, c, d,* &c. represent rays of light issuing centrifugally from the sun. A line from the sun's centre of gravity, *s*, to that of the earth, *o*, will shew the direction in which the two bodies mutually struck each other, or the line in which they would fall together, if no counteracting principle prevented it. The equal distances of the lines which represent the rays, being agreeable to the equal distribution of light through the zodiac, it may be seen that twice the quantity falls on one side of the line of direction, *s o*, as on the other; thus *a b c d* are on one side, while *e* and *f* only fall on the opposite side of the line of direction. Though this is an exaggerated proportion, yet in all the positions in which the earth stands to the sun, during its annual revolution round him, it will be found that more rays fall on one side of its axis than on the other; and the consequence of such an inequality of impulse must be its rotation on its axis, if not also of its annual revolution. The author further inquires, whether the repulsion of light may not be a balance to the gravitation of the planets towards the sun, and whether their several distances may not be produced by differences in their densities, because the larger the surface of a given quantity of matter, the more it will be repelled by the action of light? To put these ideas to the test of experiment, he had recourse to the following means: He took a circular wooden box, BB, fig. 1, plate III, and made oblique holes, represented by the tubes, in its side. This box was close, both at top and bottom, with the exception of an aperture, *a*, to admit the mouth of a double pair of bellows, to make the current of air equal. A very thin glass globe was hung by a very long thread, exactly over the centre *a*. This gave it a constant tendency towards that centre, and represented the gravitation of the planets towards the sun. The ball being now drawn to the side of the box, and the bellows blown, the box instantly began to turn on its axis, and to revolve in an ellipse. This experiment is ingeniously contrived, and will gratify those who may not be disposed to give full credence to the theory it was instituted to support; yet the theory itself is certainly more entitled to respectful attention than many that have been proposed; the present state of our knowledge does not enable us to decide against it; and it therefore remains for future investigations to establish or subvert.

Mercury. ☿

Mercury is the nearest planet to the sun, yet his distance from that luminary is not less than 37,000,000 of miles. He emits a very bright white light, always to us appears near the sun, and as he is generally lost in the splendour of the solar beams, astronomers have but scanty opportunities of making observations upon him. His diameter is 3224 miles; and his revolution round the sun is performed in 87 days 23 hours, 14 minutes, 33 seconds; his summers and winters cannot therefore be more than 44 days each. As no spots have yet been discovered on his disc, the time of his diurnal rotation is not known with certainty, though Schroeter is induced, by some of his observations, to believe that it is performed in 24 hours and 5 minutes. The position of his axis is also undetermined.

Mercury never goes to a greater distance from the sun than about 27° 5′; so that he is never longer in setting after the sun than an hour and fifty minutes; nor does he ever rise sooner than the same space of time before the sun. When he begins to make his appearance in the evening after sun-set, he can scarcely at first be distinguished on account of the twilight; but he is seen at a greater distance from the sun every successive evening, till he has attained the distance of about 22° 5′, when he begins to return again. During this interval, his motion, referred to the stars, is direct; but when he approaches within 18° of the sun, he appears for some time stationary, and then his motion begins to be retrograde, till at last his proximity to the sun prevents his being seen. Soon after, he may be perceived in the morning before sun-rise, receding further and further from that luminary, as before he disappeared. Having attained the distance of 18°, he again becomes stationary, then assumes a direct motion, but continues to separate till his distance is 22° 5′, after which he again returns to the sun, plunges into his rays, and appears soon after in the evening, after sun-set, to repeat the same career.

The inclination of Mercury's orbit, to the plane of the ecliptic, is about 7°. He may be much better observed near our equator than in high latitudes. When examined with a telescope magnifying 200 or 300 times, he exhibits the same differences of phases as the moon, being sometimes horned, sometimes gibbous, and sometimes shining almost with a round face—it is not entirely full, because his enlightened side is never turned directly towards us; but he is at all times well defined, without any ragged edge, and perfectly bright; like the moon, the crescent is always turned towards the sun. The apparent

diameter of Mercury varies with his position; it is least when the planet plunges into the solar rays in the morning, or when it disengages itself from them; it is greatest when the planet plunges into the solar rays in the evening, or when it disengages itself from them in the evening; that is, when the planet passes the sun in its retrograde motion, its diameter appears the greatest possible; and when it passes the sun into its direct motion, it is the smallest possible. Sometimes, when the planet disappears during its retrograde motion, that is, when it plunges into the sun's rays in the evening, it may be seen crossing the sun, in a right line, under the form of a black spot. This black spot is recognized to be the planet, by its position, its apparent diameter, and its retrograde motion. These transits, as they are termed, are miniature eclipses; they demonstrate that the planet is itself an opaque body, and shines only by the light it borrows from the sun. A transit of Mercury does not occur at every one of his revolutions, because his orbit is inclined to the ecliptic, and coincides with it only at the two nodes; hence the planet cannot be seen to pass over the disc of the sun, unless its nodes are in or very near the line which joins the sun and the earth. Transits of Mercury are expected in the years 1815, 1822, 1832, 1835, 1845, and 1848.

Mercury moves in his orbit about 110,000 miles per hour; the sun to him appears three times as large as to us. and affords him, at a medium, seven times the heat felt at our torrid zone. Hence it appears that if the materials of which the planet is composed were as susceptible of being heated as those of our earth, they would be either melted or vitrified, and the planet would have acquired such a brightness, as to prevent its appearing like a black spot at its transit. Why then may we not suppose that he has inhabitants as different from us as his matter?

Venus. ♀

Venus is the most beautiful star of the heavens. She is called the Morning or Evening Star, according as she precedes or follows the apparent course of the sun, and retains each title about 290 days. Her light is remarkable for its brightness and whiteness, casting a sensible shadow, and so vivid, at her greatest elongations, that she is visible to the naked eye in full day-light; and the light of the moon is frequently observed to be comparatively dull. She is the second planet from the sun, round which she performs her annual revolution, at the medium distance of 68,000,000 of miles, in 224 days, 16 hours, 41 minutes, 27 seconds. The time of her diurnal revolution,

or the length of her day, is supposed to be 23 hours, 21 minutes. It is necessary to remark, that with respect to this point, and conclusions drawn from it, there is some uncertainty. Dr. Herschel is among those observers who have not satisfied themselves as to the existence of spots on this planet, and therefore do not consider the position of her axis, and the period of her diurnal rotation, as fully determined. Her diameter is 7687 miles, and she is therefore very nearly the size of the Earth. The inclination of her orbit to the ecliptic, is about 3° 23′ 35″. Her greatest distance from the sun varies from 45° to nearly 48°.

The transits of Venus are very rare phenomena; only two, we have before observed, occurred during the last century, and another will not happen until the year 1874. During a transit, the black spot, under the form of which she appears, has an apparent diameter of 59″. A few days after this has been observed, she is seen in the morning, west of the sun, and appears through a good telescope in the form of a fine crescent, with the convexity turned towards the sun. She moves gradually westward with a retarded motion, and the crescent become more full. In about ten weeks, she has moved about 46° west of the sun, and is now a semi-circle, and her diameter is 26″. She is now stationary. She then moves eastward with a motion gradually accelerated, and overtakes the sun in 9½ months after having been seen on his disc. Some time after she is seen in the evening, east of the sun, round, but very small. She moves eastward, and increases in diameter, but loses of her roundness, till she gets about 46° east of the sun, when she is again a semi-circle. She now moves westward, increasing in diameter, but becoming a crescent, like the waning moon; and, at last, after a period of nearly 584 days, comes again into conjunction with the sun, with an apparent diameter of 59″. It may perhaps excite the surprise of some, that Venus should keep longer on the east or west of the sun, than the whole time of her period round him. But the difficulty vanishes when we consider that the earth is all the while going round the sun the same way, though not so quickly, as Venus; and therefore her relative motion to the earth must in every period be as much slower than her absolute motion in her orbit, as the earth during that time advances forward in the ecliptic, which is 220 degrees.

To the inhabitants of Venus, the sun will appear nearly twice as large as to us, and Mercury will be a morning and evening star to them, as she is to us. Her atmosphere has been calculated at fifty miles in height, from a shade appearing on the sun's face, about five seconds before the dark body of Venus

appeared to touch his edge, at the time of her transit. During the transit, also, the greatest attention was exerted to discover whether she was attended by any satellite, but none was observed, and she is therefore not known to have one.

The axis of Venus is generally supposed to be inclined 75 degrees from the axis of her orbit, which is 51½ degrees more than our earth's axis is inclined from the axis of the ecliptic; and therefore the variation of her seasons is proportionately greater. The north pole of her axis inclines towards the 20th degree of Aquarius, our earth's to the beginning of Cancer: consequently the northern regions of Venus have summer in the signs where those of our earth have winter, and *vice versâ.* As the sun's greatest declination on each side of her equator amounts to 75 degrees, her tropics are only 15 degrees from her polès, and her polar circles as far from the equator. She has at her equator two summers and two winters, in each of her annual revolutions.

The Earth. ⊕

The Earth is the next planet above Venus in the Solar System. Her distance from the Sun, is at a mean 95,000,000 of miles, and her annual revolution is performed in 365 days, 5 hours, 48 minutes, 49 seconds; this is called her *tropical year;* but the time she takes to perform an annual revolution from any fixed star to the same again, as seen from the sun, is 365 days, 6 hours, 9 minutes, 12 seconds, which is called a *sidereal year*. Her rotation on her axis is performed in 24 hours, which is called the length of a natural day. Her diameter is 7911 miles. Though she travels along her orbit at the rate of 68,000 miles per hour, a motion about 140 times swifter than that of a cannon ball, yet her motion is little more than half as swift as that of Mercury in his orbit. Her diurnal rotation being from west to east, the diurnal motion of all the heavenly bodies appears to be from east to west. Besides the 68,000 miles of progressive advance, to which the inhabitants of every part are subjected alike, the inhabitants of the equator are carried 1030 miles every hour by the earth's motion on its axis; but from the equator to the poles, this motion diminishes, and at the latitude of London, it amounts only to about 580 miles per hour.

If the axis of the earth were perpendicular to the ecliptic, or plane of its orbit, the days and nights would be of equal length in every part of it; but its axis is inclined 23½ degrees to the ecliptic, and this produces the seasons; the excessive heat

Solar system reviewed.—The Earth.

which would be felt at the equator, and the excessive cold which would be felt at the poles, being thereby both moderated. The earth's axis keeps parallel with itself, that is, constantly preserves the same oblique direction, during the whole of its annual journey, with a very small exception, to be afterwards noticed.

The following experiment will give a plain idea of the diurnal and annual motions of the earth, and the phenomena of the seasons: Take about seven feet of strong wire, and bend it circularly, as *a b c d*, fig. 2, pl. III, which being viewed obliquely, appears elliptical as in the figure. Place a lighted candle on a table; and having fixed one end of a silk thread, K, to the north pole of a small terrestrial globe H, about three inches diameter, cause another person to hold the wire circle, so that it may be parallel to the table, and as high as the flame of the candle, I, which should be in or near the centre. Then having twisted the thread as towards the left hand, that by untwisting, it may turn the globe round eastward, or contrary to the way in which the hands of a watch move, hang the globe by the thread within this circle, almost contiguous to it; and, as the thread untwists, the globe (which is enlightened half round by the candle, as the earth is by the sun) will turn round its axis, and the different places upon it will be carried through the light and dark hemispheres, and have the appearance of a regular succession of days and nights, as our earth has in reality by such motion. As the globe turns, move your hand slowly, so as to carry the globe round the candle, according to the order of the letters *a b c d*, keeping its centre even with the wire circle, and you will perceive, that the candle, being still perpendicular to the equator, will enlighten the globe from pole to pole in its whole motion round the circle; and that every place on the globe goes equally through the light and dark, as it turns round by the untwisting of the thread, and therefore has a perpetual equinox. The globe thus turning round, represents the earth turning round its axis; and the motion of the globe round the candle represents the earth's annual motion round the sun; and shews, that if the earth's axis had no inclination to the plane of its orbit, all the days and nights of the year would be equally long, consequently there would be no difference of seasons. This peculiarity distinguishes the planet Jupiter, whose inhabitants have a perpetual equinox, namely, his axis is perpendicular to the plane of his orbit, as the thread, round which the globe turns in this experiment, is perpendicular to the plane of the area inclosed by the wire. But now let the person who holds the wire, hold it obliquely in the position ABCD, raising the side ♋ just as much as he depresses

the side ♑, that the flame may be still in the plane of the circle; and twisting the thread as before, that the globe may turn round its axis in the same way it is carried round the candle, that is, from west to east; let the globe down into the lowermost part of the wire circle at ♑; and if the circle be properly inclined, the candle will shine perpendicularly on the tropic of Cancer; and the frigid zone, lying within the arctic or north polar circle, will be enlightened as in the figure; and will keep in the light, however often the globe turns round its axis. From the equator to the north polar circle, all the places have longer days and shorter nights; but from the equator to the south polar circle, just the reverse. The sun does not set to any part of the north frigid zone, as shewn by the candle's shining on it, so that the motion of the globe can carry no place of that zone into the dark; and at the same time the south frigid zone is involved in darkness, and the turning of the globe brings none of its places into the light. If the earth were to continue in the like part of its orbit, the sun would never set to the inhabitants of the north frigid zone, nor rise to those of the south. At the equator, it would be always equal day and night; and as places were gradually more and more distant towards the arctic circle, they would have longer days and shorter nights; whilst those on the south side of the equator would have their nights longer than their days. In this case there would be a continual summer on the north side of the equator, and continual winter on the south side of it. But as the globe turns round its axis, move your hand slowly forward, so as to carry the globe from H towards E, and the boundary of light and darkness will approach towards the north pole, and recede towards the south pole: the northern places will go through less and less of the light, and the southern places through more and more of it; shewing how the northern days decrease in length, and the southern days increase, whilst the globe proceeds from H to E. When the globe is at E, it is at a mean state between the lowest and highest parts of its orbit; the candle is directly over the equator; the boundary of light and darkness just reaches to both the poles, and all places on the globe go equally through the light and dark hemispheres, shewing that the days and nights are then equal at all places of the earth, the poles only excepted; for the sun is then setting to the north pole, and rising to the south pole.

Continue moving the globe forward, and as it goes through the quarter A, the north pole recedes still farther into the dark hemisphere, and the south advances more into the light, as the

globe comes nearer to ♋; and when it comes there at F, the candle is directly over the tropic of Capricorn; the days are at the shortest, and the nights at the longest, in the northern hemisphere, all the way from the equator to the arctic circle; and the reverse in the southern hemisphere, from the equator to the antarctic circle; within which circle it is for many weeks continual daylight.

Continue both motions, and as the globe moves through the quarter B, the north pole advances towards the light, and the south pole recedes towards the dark; the days lengthen in the northern hemisphere, and shorten in the southern; and when the globe comes to G, the candle will be again over the equator, (as when the globe was at E,) the days and nights will therefore again be equal, and the north pole will be just commencing her long day, while the south is left for an equal space of time in darkness.

Thus we see the reason why the days lengthen and shorten from the equator to the polar circles every year; why there is periodically no day or night for many turnings of the earth within the polar circles; why there is but one day and one night in the whole year at the poles; and why the days and nights are equally long all the year round at the equator, which is always equally cut by the circle bounding light and darkness. The inclination of an axis, or of the plane of an orbit, is merely relative, arising out of the comparison we make with some other axis or orbit, which we do not consider as inclined at all. If the axis of the earth be inclined 23½ degrees to the axis of this orbit, the axis of this orbit must be inclined 23½ degress to the axis of the earth; and it amounts to the same thing, whether we use the former expression or the latter.

Though we say that the inhabitants within the arctic and antarctic circles are at opposite times of the year deprived of the sight of the sun, yet they are not altogether deprived of his light; for the atmosphere reflecting and refracting the sun's light, forms a twilight at the distance of even 18 degrees. Hence the day breaks to us when the sun is still 18 degrees below the eastern horizon; and we have his light in the evening till he sinks 18 degrees below the western. But as the sun in summer rises considerably to the north of the east, and sets also to the north of the west with us, he rises and sets very obliquely to the horizon, and the twilight is of long duration, At midsummer, Great Britain has no night, for the whole island is within 18 degrees of the horizon, or boundary of the sun's light. In high southern latitudes, they enjoy in their

turn, the same advantage; but at the equator, the sun sinks abruptly from the horizon, because his path is at right angles to it, or very nearly so; and the quick transition from the glare of day, to utter darkness, cuts off the enjoyment of the twilight hour.

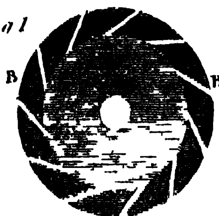
From the revolution of the earth round its axis, Sir Isaac Newton was led to suppose, that its shape was not a perfect sphere, but that of an oblate spheroid, flattened at the poles; because in revolving, its parts have a tendency to recede from the axis, from the equator particularly, consequently the poles press internally, and raise the equatorial parts, till an equilibrium occurs. Sir Isaac Newton calculated that the equatorial exceeds the polar diameter 34 miles and one-fifth; and this instance of his penetration was afterwards fully confirmed by the admeasurements and observations of two deputations of mathematicians, who visited the vicinity of the northern and southern poles in 1735, and agreed in pronouncing them flattened, making the difference between the diameters as 266 to 265, or as 179 to 178. Another proof of the flatness of the poles has been mentioned at page 277, where we have observed, that a pendulum, calculated to swing seconds at the poles, or in a high latitude, will not swing seconds at the equator unless it be shortened; therefore, as a pendulum swings by the power of gravity, that power is rather less at the equator than at the poles; partly on account of the greater distance of those parts from the equator, and partly from their greater centrifugal force, which tends to throw every thing in a tangent from its surface. If the diurnal motion of the earth were to cease, its centrifugal force would of course be destroyed at the same time, in which case, the waters of the ocean would flow towards the poles, in order to restore the perfectly globular form of the earth, and would overwhelm those regions at the same time that they retired from the shores of the equator. An experiment may easily be contrived to shew the tendency of a swift whirling motion to produce an oblate spheroid like the earth. Let two slips of pasteboard, or any tolerably flexible material, be bent into a circular form, and fitted upon an axis, as shown by fig. 3, plate III; so as to turn with that axis. When they are made to revolve very slowly by turning the winch G, the change in their form will not be perceptible; but if the winch be turned with rapidity, the poles of the hoops are depressed, and their sides bulge out.

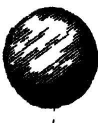
That the apparent diameter of the sun is greater in winter than in summer, is obvious to common observation. The reason is, the earth's elliptical orbit, in the lower focus of which the sun is situated, and as this point is 1,617,941 miles from

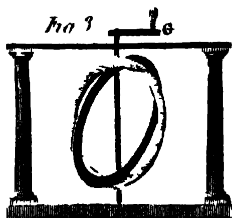
the centre of the orbit, the earth comes twice that distance, or 3,235,882 miles nearer the sun at one time of the year than another, and its nearest approach is in our winter, for it is then the sun appears under the largest angle. Hence it may be inquired, why have we not the hottest weather when the earth is nearest the sun? In the first place, it must be observed in answer, that the eccentricity of the earth's orbit, or 1,617,941 miles, bears no greater proportion to the earth's mean distance from the sun, than 17 does to 1,000; and therefore this small difference of distance is in itself of little consequence. But the principal cause of the difference between winter and summer is, that in the former season, the sun's rays fall so obliquely upon us, that any given number of them is spread over a much greater surface in the latitude in which we live. Another cause contributing greatly to the winter's cold, is the length of the nights, which carry off more heat than the sun imparts during the day. In summer, on the contrary, the sun attaining a considerable altitude, his rays dart down upon us more nearly perpendicular, a great number of them fall upon the same space, and, by their long continuance, more heat is imparted by day than can fly off by night. The atmosphere is heated, not by the passage of the sun's rays through it, but from the earth, which absorbs the rays, and when the earth is once well heated, it does not lose its temperature very readily, because the air carries off heat slowly. We have therefore a greater number of warm days, and all our hottest weather, after the longest day, though the sun's meridian altitude from that day begins to decline; and this is only stating with regard to a season, a fact of which we have diurnally a proof, viz. that it is hotter at two or three in the afternoon, when the sun has gone towards the west, than at noon when he is on the meridian. By parity of reasoning, it is equally evident, that we shall have the greatest number of cold days, and the coldest weather, after the shortest day, though after that time, the sun is actually higher every day; but the heat received by the Earth is so trifling, that the long night is not only adequate to counteract its influence, but has power enough to reduce it for some time lower and lower.

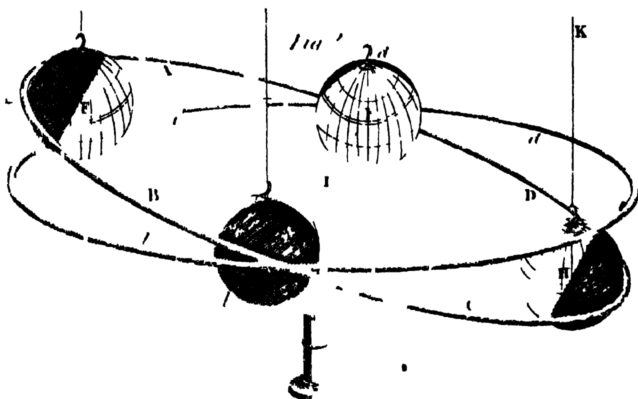
The Moon. ☾

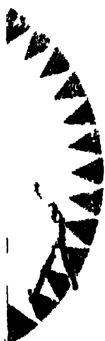
Next to the sun, the Moon appears to us the most splendid of all the heavenly bodies. Her orbit is an ellipse, with the Earth in one of its foci; her revolution round the earth is performed in 29 days, 17 hours, 44 minutes, 3 seconds, and with the earth she revolves round the sun in a year. Her diameter is 2180 miles, and her distance 240,000 miles. It is therefore

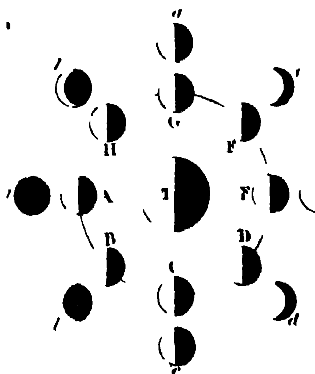

Fig 1
B
B



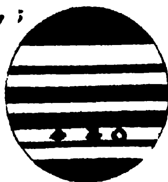

Fig 3
G


K
F
B
I
D
H




H
F
A
T
F
B
D




Fig 5

her comparative nearness to us, that makes her appear so large, and afford so much light. Her rotation on her axis is performed in the same time as her revolution round the earth, hence she always keeps the same side towards us, except that we sometimes see a little more of one side, and at other times a little more of another side. This is called her *libration*. This libration is produced by her unequal motion in her orbit, and from the difference in its direction, it is distinguished into two kinds; 1, Libration in latitude; 2, Libration in longitude. Her libration in longitude, is her seeming motion to and fro, so as to shew sometimes more of her eastern edge, and sometimes more of her western edge. Her libration in latitude, is when either of her poles appears to dip a little towards the earth.

The moon is an opaque globe like the earth, and shines only by the light she receives from the sun, and reflects to us. She therefore disappears when she comes between us and the sun, because her dark side is then towards us. Thus when she is at A, fig. 4, plate III, in conjunction with the sun S, her dark half is towards the earth, and she disappears as at *a*, there being no light on that half to render it visible. On the innermost circle, the moon is delineated as she would appear to a spectator in the sun; on the outermost circle, is shewn her appearance to a spectator on the earth at T. When she comes to her first octant at B, or has gone an eighth part of her orbit from her conjunction, a quarter of her enlightened side is towards the earth, and she appears horned as at *b*. When she has gone a quarter of her orbit from between the earth and sun to C, she shews us one half of her enlightened side as at *c*, and we say she is a quarter old. At D she is in her second octant; and by shewing us more of her enlightened side, she appears gibbous as at *d*. At E her whole enlightened side is towards the earth; and therefore she appears round, as at *e*, and we say it is full moon. In her third octant at F, part of her dark side being towards the earth, she again appears gibbous, and is on the decrease as at *f*. At G we see just one half of her enlightened side; and she appears half decreased, or in her third quarter, as at *g*. At H we only see a quarter of her enlightened side; being in her fourth octant, where she appears horned as at *h*. And at A, having completed her course from the sun to the sun again, she disappears; and we say it is new moon. Thus in going from A to E, the moon seems continually to increase; and in going from E to A, to decrease in the same proportion; having like phases at equal distances from A to E, but as seen from the sun S, she is always full.

The moon appears not perfectly round when she is full in the highest or lowest part of her orbit, because we have not a full view of her enlightened side at that time. When full in the highest part of her orbit, a small deficiency appears on her lowest edge; and the contrary when full in the lowest part of her orbit.

It is evident from the figure, that when the moon changes to the earth, the earth appears full to the moon, and *vice versâ*. For when the moon is at A, new to the earth, the whole enlightened side of the earth is towards the moon; and when the moon is at E, full to the earth, its dark side is towards her. Hence a new moon answers to a full earth, and a full moon to a new earth. The quarters are also reversed to each other.

Between the third quarter and change, the moon is frequently visible in the forenoon, even when the sun shines; and then she affords us an opportunity of trying an amusing experiment, if we can find a globular stone above the level of the eye, as suppose on the top of a gate. For if the sun shine on the stone, and we place ourselves so that the upper part of the stone may just seem to touch the point of the moon's lowermost horn, we shall then see the enlightened part of the stone exactly of the same shape with the moon, horned as she is, and inclined the same way to the horizon. The reason is plain; for the sun enlightens the stone the same way that he does the moon; and both being globes, when we put ourselves into the above situation, the moon and the stone have the same position to our eyes, and therefore we can see no more of the illuminated side of the one than of the other.

The position of the moon's cusps, or a right line touching the points of her horns, is very differently inclined to the horizon, at different hours of the same days of her age. Sometimes this line is perpendicular to the horizon; when this happens, she is in what astronomers call the *nonagesimal degree*, which is the highest point of the ecliptic above the horizon at that time, and is 90 degrees from both sides of the horizon where it is then cut by the ecliptic. But this never happens when the moon is on the meridian, except when she is at the very beginning of Cancer or Capricorn.

It is apparent to the naked eye, that the surface of the moon is irregular, from the different shades of colour which it exhibits; and when viewed through a good telescope, it appears diversified with every variety of hill and dale. In every situation of the moon, the elevated parts of her surface cast a shadow on the adjoining lower parts in the direction from the

sun, and the cavities are always dark on the side next the sun. The darker parts were at one time very generally believed to be water, but it is now generally admitted that they are deep cavities or valleys, and that the appearance of the moon's disc is such as our earth would present to her inhabitants, if the ocean was dried up. The heights of the lunar mountains were formerly supposed to be much greater than those of the earth; But Dr. Herschel has demonstrated that very few are more than half a mile high, and the highest little more than a mile. Before or after the moon is at full, the boundary of the light and dark part of the side presented to us, in consequence of the multiplicity of her caverns and mountains, appears exceedingly jagged or uneven; while, contrary to what we should expect, the real boundary of her disc, or the boundary between the hemisphere which we see, and that which is turned away from us, appears smooth and well defined, though examined with a considerable magnifying power. In explanation of this difficulty, it has been observed, that as all the parts adjoining to the real boundary or edge of the moon are full of irregularities, the elevations of some parts may stand before the hollows of others, so as to form, upon the whole, the appearance of a smooth surface, and perhaps the atmosphere of the moon may likewise contribute to this appearance.

The ruggedness of the moon's surface adds greatly to her utility as an attendant of the earth; for if her disc were free from all asperities, or covered with water, her light would only in certain situations shew us the image of the sun, apparently nothing more than a brilliant point. But her inequalities scattering the light on every side, her disc becomes entirely resplendent.

Bright specks have been observed on the dark parts of the moon's disc, and so far from the illuminated portion as not to depend on the sun's rays. These spots, becoming extinct after a certain time, have been supposed to be volcanoes. Dr. Herschel, in 1787, saw three of these volcanoes at once in the dark part of the moon: two of them were barely visible; but the third was more vivid, and exhibited an elongation like an eruption or lava of luminous matter, resembling a small piece of burning charcoal, covered by a very thin coat of ashes. If volcanoes or fire exist in the moon, it seems reasonable to conclude, that the moon has an atmosphere, and that this is the case, there is good reason to believe, though it has been much controverted, and even denied till lately. Some astronomers think that they can attribute the variable brightness of the moon, at certain

times, to no other cause than the variable state of her atmosphere, more or less loaded with vapours. Cassini observed, that Saturn, Jupiter, and the fixed stars, had their circular figures changed into elliptical ones, when they approached either the dark or the illuminated edge of the moon; and to these indications of a lunar atmosphere, Schroeter adds the following; that the two cusps or apices of the luminous horns, in a new moon, appear tapering in a very sharp and faint prolongation. He also observed that, when once Jupiter came very near the moon, two of his satellites appeared indistinct for a short time before they went quite behind the body of the moon. If the moon have really an atmosphere, still we need not be surprised at the difficulty with which it is distinguished, for it probably is extremely attenuated; Laplace indeed calculates that it must be more rare than what we call the vacuum of our best air-pumps.

Excepting the occasional changes attributed to the volcanoes and to the atmosphere of the moon, the general appearance of this luminary is constantly the same; and *selenographia*, or maps of the face of the moon, have frequently been published; the most remarkable spots in these maps, have been sometimes distinguished by the names of places on the earth, but mostly by the names of eminent persons, as Plato, Archimedes, &c. The most accurate transcript of the moon's disc is perhaps that executed by John Russel, R. A.

The moon has scarcely any difference of seasons, her axis being almost perpendicular to the ecliptic. What is very singular, one half of her has no darkness at all; the earth constantly affording it a strong light in the sun's absence; while the other half has a fortnight's darkness and a fortnight's light by turns. The earth, as before observed, acting as a moon to the moon, will from her be seen to wax and wane regularly, but will appear about 13 times as large, and afford about 13 times as much light as she does to us.

From the moon, one half of the earth is never seen; from the middle of the other half of the moon, the earth is always seen over head, turning round almost 30 times as quickly as the moon does. From the circle which limits our view of the moon, only one half of the earth's side next her is seen; the other half being hid below the horizon of all the places on that circle.

As the earth turns round its axis, the several continents, seas, and islands, appear to the moon's inhabitants like so many spots of different forms and brightness, moving over its surface; but much fainter at some times than others,

as our clouds cover them or leave them. By these spots the lunarians can determine the time of the earth's diurnal motion, just as we do the motion of the sun; and their observations will at the same time furnish them with an accurate measure of time.

The moon's axis being nearly perpendicular to the ecliptic, the sun never removes sensibly from her equator; and the obliquity of her orbit, which is next to nothing as seen from the sun, cannot cause the sun to decline sensibly from her equator. Yet her inhabitants are not destitute of means for ascertaining the length of their year, though their method and ours must differ. We can know the length of our year by the return of our equinoxes; but the lunarians having always equal day and night, must have recourse to another method; and we may suppose, they measure their year by observing when either of the poles of our earth begins to be enlightened, and the other to disappear, which is always at our equinoxes; they being conveniently situated for observing great tracts of land about the poles of our earth, which are entirely unknown to us. Hence we conclude, that the year is of the same absolute length both to the earth and moon, though very different as to the number of days; we having $365\frac{1}{4}$ natural days, and the lunarians only $12\frac{45}{118}$, the day and night in the moon being together as long as $29\frac{1}{2}$ on the earth.

The lunar rays excite no perceptible warmth, not even when concentrated upon a thermometer, by the largest burning mirror or lens. This is accounted for on the supposition of their extreme diffusion, so that we are unable to collect a sufficient quantity of them to evidence their heating effects. The calculations which have been made of the tenuity of the moon's light, differ so widely from each other, that we know not which to credit; some having asserted that it is ninety thousand, and others that it is three hundred thousand times less than that of common day-light. But all calculations founded on the supposed fact that the reflected light and heat are diminished in equal proportions, are probably fallacious: she may reflect little or no heat, yet her light may reach us in a far greater proportion than has yet been allowed.

The moon has not received more attention from the astronomer than the poet; but while the recondite speculations of the one please but few, and often almost bewilder the keenest understanding, the other depicts only those benignant effects which every eye can behold, and every heart enjoy. The following night-piece from Homer, is esteemed by Pope, its

translator, to be superemiment in the original, and it will not be denied the tribute of admiration in its English dress:

"So when the Moon, refulgent lamp of night,
O'er heaven's clear azure spreads her sacred light,
When not a breath disturbs the deep serene,
And not a cloud o'ercasts the solemn scene;
Around her throne the vivid planets roll,
And stars unnumber'd gild the glowing pole,
O'er the dark trees a yellower verdure shed,
And tip with silver every mountain's head:
Then shine the vales; the rocks in prospect rise;
A flood of glory bursts from all the skies;
The conscious swains, rejoicing in the sight,
Eye the blue vault, and bless the useful light."

Mars. ♂

The next planet beyond the earth in the solar system, is Mars, whose distance from the sun is 144,000,000 of miles, and who requires nearly 687 days to complete his annual revolution. The colour of this planet is a dusky red, an appearance attributed to the great density of his atmosphere, which permits only the red rays to be reflected to us. From the spots which have been observed on his disc, his rotation on his axis has been ascertained to be performed in 24 hours, 39 minutes, 22 seconds, and the inclination of his axis to his orbit is 59° 22′. His equatorial is to his polar diameter as 16 to 15, and his mean diameter is 4189 miles.

Mars is not subject to the same limitation in his motion as Mercury or Venus, but appears sometimes very near the sun, and at other times at a great distance from him; sometimes rising when the sun sets, or setting when the sun rises. He sometimes appears gibbous, but never horned, like the moon, a proof that his orbit includes that of the earth, and that he shines by a borrowed light. When he is opposite to the sun, or when we see him on the meridian at midnight, he is much more brilliant than in another situation, being five times nearer to us than at a conjunction.

The sun affords to Mars only about a third of the light he affords to the earth, and it has therefore been thought singular, that he has not been discovered to have a moon; but perhaps he is compensated for this apparent want, and the light he receives may be prolonged, by the height and density of his atmosphere, which is so remarkable, that when he approaches any of the fixed stars, they change their colour, grow dim, and often become nearly invisible, though at some little distance from the body of the planet.

Mars appears to move from west to east round the earth, but his apparent motion is very unequal. When we first perceive him in the morning, separating from the sun, his motion is the most rapid; but this rapidity diminishes gradually, and ceases altogether when the planet is about 137° distant from the sun; then his retrograde motion commences, and increases in rapidity till he comes into opposition with the sun. It then gradually diminishes again, till the planet is within 137° of the sun; it then becomes direct, till at last the planet is lost for a time in the evening rays of that luminary. As his distance from us is so different at different times, so is his apparent diameter, which at a mean is 27″, but when in opposition, his apparent diameter is 81″.

Besides the dark spots, which serve to determine the diurnal revolution of Mars, several early astronomers took notice that a segment of his globe about the south pole exceeded the rest of his disc so much in brightness, as to appear as if it were the segment of a larger globe. Maraldi informs us, that this bright spot had been taken notice of for sixty years, and was more permanent than the other spots on the planet. One part of it is brighter than the rest, and the least bright part is subject to great changes, and has sometimes disappeared. A similar brightness about the north pole was also sometimes observed, and these observations are now confirmed by Dr. Herschel, who has viewed the planet with much better instruments, and much higher magnifying powers, than any other astronomer. "The analogy," says the Doctor, "between Mars and the earth, is by far the greatest in the whole solar system. Their diurnal motion is nearly the same; the obliquity of their respective ecliptics not very different. Of all the superior planets, the distance of Mars from the sun is by far the nearest alike to that of the earth; nor will the length of the Martial year appear very different from what we enjoy, when compared to the surprising duration of the years of Jupiter, Saturn, and the Georgium Sidus. If then we find that the globe we inhabit has its polar region frozen and covered with mountains of ice and snow, that only partly melt when alternately exposed to the sun, I may well be permitted to surmise, that the same causes may probably have the same effect on the globe of Mars; that the bright polar spots are owing to the vivid reflection of light from frozen regions, and that the reduction of those spots is to be ascribed to their being exposed to the sun. In the year 1781, the south polar spot was extremely large, which we might well expect, as that pole had but lately been involved in a whole twelvemonth's darkness and absence from the sun; but in 1783, I found it considerably

smaller than before, and it decreased continually from the 20th of May, till about the middle of September, when it seemed to be at a stand. During this last period, the south pole had already been above eight months enjoying the benefit of summer, and still continued to receive the sun-beams, though, towards the latter end, in such an oblique direction as to be but little benefited by them. On the other hand, in the year 1781, the north polar spot, which had been its twelvemonth in the sunshine, and was but lately returning into darkness, appeared small, though undoubtedly increasing in size. Its not being visible in the year 1783, is no objection to these phenomena, being owing to the position of the axis, by which it was removed out of sight."

Vesta.

This small planet was discovered by Dr. Olbers, of Bremen, on the 29th of March, 1807. Its diameter is about 238 miles. Its distance from the sun is almost 215,000,000 of miles, and its annual revolution round the sun is performed in 1335 days. The inclination of its orbit to the ecliptic is 7°. Examined by Dr. Herschel, with an excellent fifteen-feet reflector, and a power of 300, it exhibited no appearance of a disc, but appeared like a fixed star of the sixth magnitude; that is, it was nearly a point, with an intense radiating light. When the sky was clear, it might be discerned with the naked eye.

Juno.

This is another small planet, which was discovered by Harding, of Lilienthal, on the 1st of September, 1803. Its diameter is 1425 miles, its distance from the sun 243,000,000 of miles; and its annual period 1590 days. The inclination of its orbit to the ecliptic is 14°.

Ceres.

This planet was discovered on the 1st of January, 1801, by Piazzi, an Italian astronomer, whose name it not unfrequently receives. Its distance from the sun is nealy 263,000,000 of miles. Its diameter is only about 163 miles. The time of its diurnal motion is unknown; but its annual sidereal revolution is calculated, by Laplace, to be performed in 1681 days, 17 hours, 57 seconds. The inclination of its orbit to the ecliptic is about 11° 48'. It appeared to Herschel of a ruddy colour, but not very deep; and he is of opinion that it has an atmo-

sphere. Its disc seldom appears well defined, apparently because a very slight degree of an unfavourable state in our atmosphere, for viewing it, affects its feeble light.

Pallas.

This planet was also discovered by Dr. Olbers, of Bremen, on the 28th of March, 1802. Its distance from the sun is nearly 264,000,000 miles; its sidereal period is 1681 days, 17 hours, 57 seconds; and its diameter is only 80 miles, so that it is the smallest known planet of the Solar System. The inclination of its orbit to the ecliptic amounts to about 38°. It is of a dusky whitish colour, and appears very indistinct with a power of 500, unless the atmosphere be remarkably clear.

Dr. Olbers received from the French National Institute, Lalande's prize of 10,000 francs (£417) a sum appropriated to the person whose labours most contributed to the promotion of astronomical knowledge, in the year of its discovery.

The orbits of the Ceres and Pallas would have been most properly represented in the plate of the Solar System, by circles of nearly equal size, but with their centres a little on opposite sides of that of the sun.

Soon after the Ceres and Pallas had been discovered, Dr. Herschel published some observations upon them; and taking into consideration their great deviation from the zodiac, or track of the planets previously known, he observed, that if they were admitted into the order of planets, we must give up the zodiac; for by extending it to them, should a few more be discovered, still farther deviating from the path of the earth, we might soon be obliged to convert the whole firmanent into a zodiac, that is, we should have none at all. Hence he proposed the name of *asteroids*, for planetary bodies of the description in question; and made the definition of that term so comprehensive, as to include all that were likely to be discovered: and he distinctly stated his belief that more planetary bodies deviating from the zodiac would be discovered: a conjecture which was realized in a short time by the discovery of the Juno and Vesta. Dr. Thompson, in his History of the Royal Society, of which society Dr. Herschel is an illustrious member, intimates his disapprobation of the term asteroids, observing that he can see no reason why the stars it is intended to designate ought not to be called planets, unless it were to prevent their discoverers from ranking so high as the discoverer of the Georgium Sidus. This insinuation appears too gratuitous to be considered either generous or just.

Jupiter. ♃

Jupiter is the largest of all the planetary bodies, and next to Venus, appears to us the brightest. His prodigious distance, which is 490,000,000 of miles from the sun, is the reason of his apparent size being less than that of Venus, though his real magnitude is above 1500 times greater, his diameter being 89,170 miles. The length of his year is 4330 days, 14 hours, 39 minutes, 2 seconds. His diurnal rotation is performed in the short space of 9 hours, 55 minutes, 37 seconds. This rotation is so amazingly rapid, that it carries his equatorial inhabitants 28,800 miles every hour, which is nearly 4000 miles more than the inhabitants of our earth's equator are carried by the same motion in 24 hours, and almost equals the hourly advance in his orbit. The remarkable spot, by the motion of which Jupiter's rotation on his axis was determined, appeared in 1694, and was lost till the year 1708, when it reappeared, on the same part of his face, and has been occasionally seen ever since.

From the greater rapidity of his diurnal rotation, his figure is that of a much flatter oblate spheroid than the earth, his equatorial being to his polar diameter as 13 to 12, a proportion which makes the former measure 6000 miles more than the latter. His axis is very nearly perpendicular to the plane of his orbit, so that his inhabitants have no perceptible change of seasons. If his axis had been inclined any considerable number of degrees, just so many degrees round each pole would alternately be involved in darkness for almost six of our years together; and as each degree of a great circle of Jupiter contains at the least 800 of our miles, the tracts of land thus deprived of the sun, would be immense. The sun appears to him only a fifth of the size he does to us, and his light and heat are only a twenty-fifth of ours. But his night is on no part of his surface five hours long; at his polar regions, the sun never sets, he enjoys a perpetual spring, and he has the splendid attendance of four moons, one or more of which are always visible to enliven his short night. It is easy, from all these circumstances, to conceive, that this spacious orb may be the residence of a race of beings very little dissimilar to ourselves.

When Jupiter is viewed through a good telescope, we perceive a number of zones or belts, of a darker colour than the rest of his disc. They are generally parallel to his equator, which is very nearly parallel to the ecliptic, but in other respects are subject to great variations. Sometimes only one

can be perceived, at other times eight. They are sometimes not parallel to one another, and their breadth is very variable, one belt having been observed to grow narrow, while another in its neighbourhood has increased in breadth, as if the one had flowed into the other; and in this case Dr. Long observes that a part of an oblique belt lay between them, as if to form a communication for this purpose. The time of their continuance is very uncertain; sometimes remaining unchanged for three months; at others, new belts have been formed in an hour or two. The continuity of the belts is sometimes interrupted, so as to give them a broken appearance. The spots and belts seen on the 7th of April, 1792, are represented by fig. 5, pl. III. The belts and spots are considered to be the body of the planet, and the light parts the clouds, transported by the winds with different velocities, and in different directions.

The four satellites of Jupiter are distinguished by their situation, that being called the first which is nearest to its primary. Their periods and distances are as follows:

	Day.	h.	m.	s.		Miles.
1st satellite revolves in	1	18	27	33	at the distance of	259,170
2nd	3	13	13	42	..	412,352
3rd	7	3	42	33	..	657,735
4th	16	16	32	8	..	1,156,640

These satellites move round Jupiter from west to east, and their orbits are supposed to be ellipses, though the eccentricity of all of them is too small to be measured, except that of the fourth; and even this amounts to more than 0,007 of its mean distance from the primary. The motions of the first three satellites, Laplace has observed, are related to each other by a most singular analogy. The mean sidereal or synodical motion of the first, added to twice that of the third, is constantly equal to three times the mean motion of the second. And the mean sydereal or synodical longitude of the first, minus three times that of the second, plus twice that of the third, is always equal to two right angles.

When the satellites fall into the shadow of the primary, we loose sight of them for a time, and they are said to be eclipsed. The three nearest are eclipsed every revolution; but the orbit of the fourth is so much inclined, that it passes by its opposition to Jupiter, without falling into his shadow, two years in six. From the singular analogy, above alluded to, it follows that (for a great number of years at least) the first three satellites cannot be eclipsed at the same time: for in the simul-

taneous eclipses of the second and third, the first will always be in conjunction with Jupiter, and *vice versâ*. By these eclipses, has been discovered the velocity of light, (see Optics,) and they serve a still more important purpose,—that of determining the longitude of places on the earth, with great facility and certainty. The longitude of a place is its distance east or west from another, reckoned in degrees of the equator, and it can always be ascertained with certainty, provided we know the time of the day at the place from which we reckon, as well as that of the place where we make the observation. Since by the motion of the earth round its axis, every point on its surface describes the circumference of a circle, or 360°, in twenty-four hours, it must consequently describe 15° in one hour, because 15 is a 24th part of 360. Hence the difference of longitude may be converted into time, by allowing one hour for every 15°, and proportionally for minutes and seconds; or conversely, with equal ease, difference of time may be converted into longitude. Voyagers, therefore, if provided with a faultless timekeeper, set at their departure exactly to the time of the place from which they sailed, may at any time ascertain their longitude, or distance east or west from that place, with great facility. Timekeepers are, however, subject to so many causes of imperfection, that they cannot be depended on, for any long period: but as the eclipses of Jupiter's satellites are more numerous than the days of the year, and Jupiter can be seen for eleven months in the year, and as there is generally one, and often two or three in one night, the observation of them may be made to answer the same purpose as a timekeeper. For example, the exact times at which the eclipses of Jupiter's satellites will occur, at the meridian of Greenwich, are given for several years to come, in the nautical ephemeris; let a person then, at any distance east or west from Greenwich, notice the eclipse of a satellite, and compare it with the time given for the same eclipse in his tables; he then perceives at once the difference of time, and consequently his longitude. To observe these eclipses with precision, does not require a telescope of great power; but the principal disadvantage of the plan at sea arises from the motion of the ship.

Saturn. ♄

Saturn is next to Jupiter in order from the sun, and the next to that planet in magnitude. His distance from the sun is 900 millions of miles, and therefore we may readily account for the paleness and feebleness of the light he reflects to us, and that he can hardly be distinguished from a fixed star by

the naked eye. His diameter is 79,042 miles, and he employs 10,746 days, 19 hours, 16 minutes, 15 seconds, in revolving once round the sun, so that the length of his year is almost thirty of ours. His diurnal rotation is believed to be performed in 10 hours, 16 minutes, 2 seconds; but the spots, the motion of which determine this point, are not well defined. The inclination of his orbit to the ecliptic is about 2½ degrees; but the inclination of his axis to his orbit is supposed to be 60°.

Saturn, when viewed through a good telescope, makes a more remarkable appearance than any of the other planets. He has belts, somewhat like those of Jupiter, though fainter: but his distinguishing characteristic is a broad, double, luminous ring, entirely surrounding him. The appearance of the planet through a good telescope is shewn by fig. 6, plate III. The ring is detached from his body in such a manner, that the distance between the innermost part of the ring and the body of the planet is equal to its breadth. Both the outward and inward rim of the ring is projected into an ellipsis, more or less oblong, according to the different degrees of obliquity with which it is viewed. Sometimes our eye is in the plane of the ring, and then it becomes invisible even when sought for with very good telescopes, probably because it is in that position too thin to subtend a sufficient angle, at such a distance. But sometimes it may be detected with a telescope of peculiar excellence, and a favourable night, and then it appears like a very slender ray of light across the disc of the planet. As the plane of this ring is always parallel to itself, that is, its situation in one part of the orbit is always parallel to that in any other part, it disappears about every 15 years, or twice in every revolution of the planet, which sometimes appears quite round for nine months together. At other times, the distance between the body of the planet and the ring is very perceptible, so that stars may be seen through it.

When Saturn appears round, if our eye be elevated above the plane of the ring, a shadowy belt will be visible, caused by the shadow of the ring, as well as by the interposition of part of it between the eye and the planet. The shadow of the ring is broadest when the sun is most elevated, but its obscure parts appear broadest when our eye is most elevated above the plane of it. When it is seen double, the ring next the body of the planet appears brightest. When the ring appears of an elliptical form, the parts about the ends of the largest axis are called the *ansæ*. These, a little before and after the disappearing of the ring, are of an unequal magnitude; the largest ansa

is longer visible before the planet's round phase, and appears again sooner than the other. Herschel demonstrates, that the ring revolves in its own plane, in 10h. 32′ 15.4″. This philosopher has paid great attention to Saturn's ring. According to him, there is one single, dark, considerably broad line, belt, or zone, which he has constantly found on the north side of the ring. As this dark belt is subject to no change whatever, it is probably owing to some permanent construction of the surface of the ring: this construction cannot be owing to the shadow of a chain of mountains, since it is visible all around on the ring; for there could be no shade at the ends of the ring; and a similar argument will apply against the opinion of very extended caverns. It is pretty evident that this dark zone is contained between two concentric circles, for all the phenomena correspond with the projection of such a zone. The nature of the ring the Doctor thinks no less solid than that of the planet itself, and it is observed, as above mentioned, to cast a strong shadow on the planet. The light of the ring is also generally brighter than that of the planet, for the ring appears sufficiently bright, with a telescope that affords scarcely light enough to see Saturn. He concludes that the edge of the ring is not flat, but spherical, or spheroidal. The dimensions of the ring, or of the two rings with the space between them, he estimates as follows:

	Miles.
Inner diameter of the small ring	146,345
Outside diameter of ditto	184,393
Inner diameter of the larger ring	190,248
Outside diameter of ditto	204,883
Breadth of the inner ring	20,000
Breadth of the outer ring	7,200
Breadth of the vacant space or dark zone	2,839

If this ring be opaque, as the sun shines fifteen years on its north side, and the same time on its south side, it will have equal day and night, each fifteen years long.

The swiftness of Saturn's motion on his axis produces an oblate figure; and his equatorial diameter is calculated to be to his polar diameter, as 11 to 10.

The sun scarcely affords to Saturn an eightieth part of the direct light that we receive from him; but this planet, besides his magnificent ring, is accompanied by not less than seven satellites, which revolve round him beyond his ring. The

periods of these satellites, and their distances from their primary, are as follows:

	d.	h.	m.	s.		Miles.
1st satellite revolves in	1	21	18	27	at the distance of	170,000
2nd	2	17	41	22	..	217,000
3d	4	12	25	12	..	303,000
4th	15	22	41	13	..	704,000
5th	79	7	48	0	..	205,000
6th	1	8	53	9	..	135,000
7th	0	22	40	46	..	107,000

The satellites of Jupiter, we have observed, are enumerated and distinguished in a regular manner, beginning at the one nearest the primary; so that the second satellite is the second in size and distance, and so of the rest. This, it appears above, is not exactly the case with the satellites of Saturn, and the reason is, that the first five satellites were discovered in 1685 by Cassini and Huygens; no more were supposed to exist, and they were called the 1st, 2nd, 3d, &c. reckoning from the planet; but, about a century afterwards, Dr. Herschel discovered two others, which were smaller and nearer to the planet; these ought therefore to have been called the first and second, and the numerical order of the others changed, so that the fifth would have become the seventh. But to avoid the confusion that might arise, in reading astronomical works, written previous to the Doctor's discovery, the anomaly of their enumeration was allowed, and they are constantly reckoned the sixth and seventh.

The inclinations of the orbits of the first, second, third, and fourth satellites, to the ecliptic, are from 30° to 31°. That of the fifth, is from 17° to 18°. This satellite is further remarkable for being the only one of the solar system, except our own, that has been observed to have any spots. From these spots, its rotation on its axis has been determined; and it is singular, that, like the moon, it revolves round its axis in the same time that it revolves round its primary.

The satellites of Saturn are frequently eclipsed, and these eclipses would be of the same use as those of Jupiter, for discovering the longitude of places on the earth, but their vast distances render them so much less susceptible of accurate observation.

The Herschel. ♅

At the distance of 1800 millions of miles from the sun, the planet Herschel, the last of the system, advances in his course. This planet was discovered by Dr. Herschel, on the 13th of March, 1781, and though commonly distinguished by his name, it is also known by other appellations; the discoverer himself called it the Georgium Sidus, or Georgian Planet, in honour of his sovereign; Lalande, and the rest of the French philosophers after him, called it the Herschel; while the Germans, preferring the ancient mode of following the heathen mythology, called it Uranus, who, in fabulous history, was the father of Saturn. The Herschel seems the name most likely to content all parties; the public voice, where the evidence is clear, is always in favour of those who have the strongest claim to distinction: the English will not relinquish both the names which may indicate the country where the discovery was made; and foreign philosophers, while they willingly give the honour to one of their own republic, are not disposed to give it to any particular king. Galileo, who discovered the four satellites of Jupiter, called them *Medicean stars*, in honour of the family of the Medici, his patrons; but the title is now almost forgotten, and never used.

The Herschel is 35,112 miles in diameter, and performs its annual revolution in 30,637 days, 4 hours, that is, very nearly eighty-four of our years. The period of its diurnal rotation has not been determined. On a clear evening, it may be seen by the naked eye, in the absence of the moon; when viewed through a good telescope, it is of a bluish white colour, and its disc is well defined. The light and heat which it receives directly from the sun is about the 362nd part of what we enjoy.

When the discoverer of the Herschel first observed it, he supposed it to be a comet; but it was soon proved to be a planet, the suspicion of which was naturally suggested by its nearness to the ecliptic. It had always been considered a fixed star, on account of the slowness of its motion; and it was no sooner known to be a planet, than it was perceived to be the star marked 34 in Flamsteed's catalogue, and 964 in Meyer's. By these means, astronomers were in possession of a whole century of observations respecting it.

Dr. Herschel had the singular merit of not only discovering this star to be a planet,but of discovering all the satellites it is supposed to have, and which are six in number. These satellites cannot be seen without a powerful telescope. Their periods of revolution round their primary, and their distances from it, are as follows:

	D.	h.	m.		Miles.
1st satellite revolves in	5	21	25,	at the distance of	230,334
2nd	8	18	0	..	298,838
3d	10	23	4	..	348,398
4th	13	12	0	..	399,434
5th	38	1	49	..	798,920
6th	107	16	40	..	1,597,736

These satellites move in a plane nearly perpendicular to the plane of the planet's orbit, and contrary to the order of the signs.



The following Synopsis of the planetary system, will enable the reader to compare the corresponding circumstances of the planets with each other, and to refer to them with facility:

Distances of the Planets from the Sun in English miles.

Mercury	37,000,000
Venus	68,000,000
Earth	95,000,000
Mars	144,000,000
Vesta	215,000,000
Juno	243,000,000
Ceres	263,000,100
Pallas	264,000,000
Jupiter	490,000,000
Saturn	900,000,000
Herschel	1,800,000,000

Diameter of the Sun and Planets in English miles.

Sun	883,246
Mercury	3,224
Venus	7,687
Earth	7,911
Moon	2,180
Mars	4,189
Vesta	238
Juno	1,425
Ceres	163
Pallas	80
Jupiter	89,170
Saturn	79,042
Herschel	35,112

Density of the Sun and Planets, that of Water being 1.

Sun	$1\frac{2}{15}$
Mercury	$9\frac{1}{6}$
Venus	$5\frac{11}{15}$
Earth	$4\frac{1}{2}$
Mars	$3\frac{2}{7}$
Jupiter	$1\frac{1}{24}$
Saturn	$\frac{13}{32}$
Herschel	1+

Quantity of Matter in the Planetary bodies, the Earth being 1.

Sun	329.630
Mercury	0.135
Venus	0.135
Earth	1.000
Moon	0.025
Jupiter	330.600
Saturn	103.950
Herschel	16.840

Number of feet per second through which a heavy body would fall at the surface of the Sun, and of each of these Planets.

Sun	450
Mercury	12
Venus	28
Earth	16+
Moon	3
Jupiter	42
Saturn	15
Herschel	4.2

Rotation of the Sun and Planets round their axes.

	D.	h.	M.	s.
Sun	25	10	0	0
Venus	0	23	21	0
Earth	0	24	0	0
Mars	0	24	39	22
Jupiter	0	9	55	37
Saturn	0	10	16	2
Saturn's Ring	0	10	32	15
Moon, a lunation, at a mean	29	12	44	3

Tropical Revolutions of the Planets round the Sun.

	D.	h.	m.	s.
Mercury	87	23	14	33
Venus	224	16	41	27
Earth	365	5	48	49
Mars...................	686	22	18	27
Jupiter................	4,330	14	39	2
Saturn	10,746	19	16	15
Herschel	30,637	4	0	0
Moon *(round the earth)* ..	27	7	43	5

Of Comets.

We have yet to mention a numerous class of bodies, which frequently appear within the limits of the planetary orbits, and some or all of which certainly belong to the solar system. We allude to comets, respecting the nature, number, and use of which the opinions of philosophers have been exceedingly divided, and very little has yet been determined in a satisfactory manner, unless it be the manifest truth, that they are not to be considered, as formerly, the portentous heralds of calamities to mankind. They are, doubtless, noble parts of the creation, traversing their appointed course, without any connection with the earth, except as parts of the same whole; and the appearances they present to us arise only from peculiarities of their constitution, indispensable probably to the comforts of their inhabitants.

The curves in which comets move are generally considered to be very eccentric ellipses, so that comets can only be seen during their vicinity to the sun, and are invisible to us during the greater part of their course. Their periodical times are so very long, and so difficult to be ascertained, that very few of them have been observed twice, and when their appearance agrees with the time foretold, it is almost impossible to identify them. Their appearances are very different. Some of them resemble a faint vapour; others have a perceptible nucleus or solid part in the middle. When they approach near the sun, they put forth the appearance of a beard or tail of luminous matter, which is differently denominated according to their position. When the comet is eastward of the sun, and moves from the sun, it is said to be *bearded*, because the luminous elongation goes before it. When the comet is westward of the sun, and sets after him, it is then said to have a *tail*, because the luminous elongation follows it;

and when the earth happens to be directly between the sun and the comet, then the train of light is so much hidden by the body of the comet, that only a little of it can be seen on each side of the comet, which is therefore said to have a *coma* or hairy appearance.

The more conspicuous comets have been long known to the vulgar under the appellation of *blazing stars;* but many of them are only to be seen by the help of telescopes, and are discovered by accident, because they appear and disappear in a few nights, and traverse the heavens in every direction. The actual motion of some of them is from east to west, while others, like the planets, move from west to east. Some of them move in the plane of the ecliptic, or within the zodiac; whilst others go in different directions, even perpendicular to the ecliptic.

Kepler and some other philosophers were of opinion that comets were in reality nothing more than a congeries of vapours, or exhalations from the sun and planets; but Sir Isaac Newton proved the absurdity of this hypothesis, by shewing that no vapours or exhalations could subsist in the regions where they were found to be the brightest; that is, very near the sun. The heat of the sun is as the density of his rays, or reciprocally as the squares of the distances of places from the sun. Therefore, as the distance of the comet of 1680, in its perihelion, December the 8th, was observed to be to the distance of the earth from the sun nearly as 6 to 1000; the sun's heat at the comet, was to his heat with us at midsummer as 1,000,000 to 36; or 28,000 to 1. Now the heat of boiling water is little more than three times the heat of our dry earth, when exposed to the midsummer's sun; assuming then the heat of red-hot iron to be about three or four times as great as boiling water, Newton concludes, that the heat of the dried earth, or body of the comet in its perihelion, must be nearly 2000 times as great as that of red-hot iron. He computes, that a globe of red-hot iron, of the dimensions of our earth, would scarcely be cool in 50,000 years. If then the comet be supposed to cool 100 times as fast as red-hot iron, yet, since its heat was 2000 times greater, supposing its magnitude to be equal to that of the earth, it would not be cool in a million of years. Upon the whole, therefore, he concluded that the comets were compact, solid, fixed, and durable bodies, in one word, a kind of planets, which move in very oblique orbits, every way with the greatest freedom; persevering in their motions, even against the course and direction of the planets; that their tail is a very thin vapour, emitted by the head or nucleus of the comet, ignited or heated by the sun; and he entertained and announced the grand idea that they might re-appear at every revolution.

Frequently a nucleus cannot be discerned: of sixteen comets observed by Dr. Herschel, fourteen were of this description; and the other two had only a very ill-defined central light, which perhaps might be called a nucleus, but not a disc. It is this want of a well-defined disc or nucleus, that renders many of the observations on comets uncertain.

From observations of the comet of 1680, Sir Isaac Newton found, that the vapour in the extremity of the tail, January 25th, began to ascend from the head before December 11th, and had therefore spent more than forty-five days in its ascent; but that all the tail which appeared December 10th, ascended in the space of those two days, then just past since its perihelion. The vapour, therefore, at the beginning, when the comet was near the sun, ascended with a prodigious swiftness; and afterwards continued to ascend with a motion retarded by the gravity of its particles, and by that ascent increased the length of the tail; but the tail, notwithstanding its length, consisted almost wholly of vapours, which had ascended from the time of its perihelion; and the vapour which ascended first, and composed the extreme of the tail, did not vanish till it was too far from the sun to be illuminated by him, and from us to be visible. Hence, also, the tails of comets that are shorter, do not ascend with a quick and continual motion from the head, and then presently disappear; but are permanent columns of vapours and exhalations, gathered from the head, by a very gentle motion, and a great space of time; which yet, by participating of that motion of their heads they had at the beginning, continue easily to move along with their heads through the celestial regions.

The ascent of the vapours from a comet, will be promoted by their circular motion round the sun, and will endeavour to recede from the sun, as smoke recedes from a fire; and therefore, the more the comets advance into the dense atmosphere of the sun, their tails will be the greater. The vapours being thus dilated, rarefied, and diffused throughout all the celestial regions, Newton thought they might probably, by little and little, through their own gravity, be attracted down to the planets, and become intermingled with their atmospheres, to which they would furnish fresh accessions of pure particles, and supply the loss of air and moisture sustained by the processes of life and vegetation. Another use he supposed comets may be designed to serve, is that of supplying the sun with fresh fuel. This may happen from their suffering a diminution of their projectile force, when in perihelion, from the resistance of the solar atmosphere; so that by degrees, their gravitation towards the sun may

be so far increased as to precipitate their fall into his body. Thus, also, fixed stars which have been gradually wasted, may be supplied with fresh fuel, acquire new splendour, and be taken for new stars: of this kind may be supposed those fixed stars which appear on a sudden, or shine at first with a surprising brightness that gradually decays, till they disappear. If this theory were true, the comets might be regarded as the conservators of the solar system, while it was shewn, at the same time, how little cause there was for that superstitious dread of their appearance, which had prevailed so generally among the ignorant of all creatures. The ideas which Sir Isaac Newton entertained of comets, were certainly far removed from the current opinions even of philosophers in his day, and we cannot say that the investigations of the century since they were published, have carried us much beyond them, though substantial objections may be offered to some parts of his hypothesis. The idea of the periodical revolutions of the comets is extremely likely to be confirmed, but the supposition that the planets are supplied with pure air and moisture diffused by them, the late discoveries in chemistry render exceedingly doubtful, by shewing abundant other means of nature's repletion in these respects. Modern chemistry indisputably proves to us, that water is composed of two invisible gases; and that by the operations constantly going on in nature, it is produced, resolved into its elements, and reproduced: on the one hand, water produces air; on the other, air produces water: under certain circumstances, water unites in a solid form with various substances; under other circumstances, it is liberated from its solid form, and assumes that of vapour or air. These operations, there is reason to believe, balance each other; the atmosphere and the water, though constantly changing, remain constantly the same in quantity, or as nearly so as the existence of mankind requires; and we find it impossible to point out the source of a decay or the need of a foreign supply. With respect to the supply of combustible matter which comets may afford to the sun, and the cause which Sir Isaac Newton, as above stated, has assigned for their falling into it, we may consider, that if on the one hand the density of the solar atmosphere has a tendency to lessen the projectile force of a comet passing through it, that tendency, it is reasonable to suppose, will be simultaneously checked and overcome, by the greater momentum with which the rays fall upon the comet. It is further to be considered, that if the comets are to be regarded merely as fuel for the sun, it were inconsistent to suppose them at the same time to be habitable worlds.

Is it not then at least reasonable to adopt the opinion, that the comets are co-existent with the planets; and that the sun's waste of matter is supplied by other means than their destruction?

Rowning, who is not satisfied with Sir Isaac Newton's theory of comets, accounts for their tails in the following manner: It is well known, that when the light of the sun passes through the atmosphere of any body, as the earth, that which passes on one side is by the refraction thereof made to converge towards that which passes on the opposite one; and the convergency is not wholly effected either at the entrance of the light into the atmosphere, or at its going out; but begining at its entrance, it increases in every point of its progress. It is also agreed, that the atmospheres of comets are very large and dense. He therefore supposes that by such time as the light of the sun has passed through a considerable part of the atmosphere of a comet, the rays are so far refracted toward each other, that they then begin sensibly to illuminate it, or rather the vapours floating in it; and so render that part they have yet to pass through visible to us: and that this portion of the atmosphere of a comet, thus illuminated, appears to us in the form of a beam of the sun's light, and passes under the denomination of a comet's tail. Some comets have had tails extending 80 millions of miles.

This opinion, that the comet's tail is merely an optical appearance, produced by the light streaming through a dense and very extensive atmosphere, is at the least exceedingly specious. If the tail be nothing but light, we can readily account for its not distorting the rays from the smallest star seen through it; and it is not difficult to admit that such an atmosphere must render the solid opaque body of the comet very indistinct, if not altogether invisible. This theory of comets it has been proposed to elucidate by experiment: Take a glass globe, suspend a small opaque globe in the middle of it, and then expose it to a strong stream of light, as from a fire or a number of candles, while it is so placed in an aperture of a wall or door, that the light which passes through it may be seen in a darkened room: but the imitation of the cometary phenomena will not be good, from the envelope of the glass, nor equal to what it would be if the water were in a state of vapour.

Kepler's law of the analogy between the periodical times of the planets, and their distances from the sun, is applicable also to the comets. Hence the mean distance of a comet from the sun may be found by comparing its period with the time of the earth's revolution round the sun: thus the period of the comet that appeared in 1531, 1607, 1682, and 1759, being about 76

years, its mean distance is found by this proportion: as 1, the square of one year, the earth's periodical time, is to 5776, the square of 76, the comet's periodical time, so is 1,000,000 the cube of 100, the earth's mean distance from the sun, to 5,776,000,000 the cube of the comet's mean distance; the cube root of which is 1794, the mean distance itself, in such parts as the mean distance of the earth contains 100. If the perihelion distance of this comet, 58, be taken from 3588, double the mean distance, we shall have the aphelion distance 3530 of such parts as the distance of the earth contains 100; and this is a little more than 35 times the distance of the earth from the sun. By a like method, the aphelion distance of the comet of 1680, comes out 138 times the mean distance of the earth from the sun, supposing its period to be 575 years; so that this comet, in its aphelion, goes to more than fourteen times the distance of Saturn from the sun.

Dr. Halley compiled a table of the elements of comets, according to the best information he could obtain; the end for which he compiled this table, he observes, was this, that whenever a new comet shall appear, we may be able to know, by comparing together the elements, whether it be any of those which have appeared before, and consequently to determine its period, and the axis of its orbit, and to foretell its return. He asserted his belief that the comet which Appian observed in the year 1531, was the same with that which Kepler and Longomontanus more accurately described in the year 1607; and which he himself observed in the year 1682. All the elements agreed, and nothing appeared to contradict his conclusion but a trifling inequality of the periodic revolution. This, he remarked, might arise from physical causes; for the motion of Saturn is so disturbed by the rest of the planets, especially Jupiter, that the periodic time of the planet is uncertain for some whole days together. How much more therefore will a comet be subject to such like errors, which rises almost four times higher than Saturn, and whose velocity, though increased but very little, would be sufficient to change its orbit from an ellipsis to a parabola. On looking over the histories of comets, he found that one had been seen in the year 1456, and also in the year 1305, which latter year he considered to be at the distance of a double period from the former. From all these considerations, he ventured to foretell that the return of the comet would take place about the year 1758. The effect of Jupiter he computed would increase its periodic time above a year, in consequence of which he predicted its return at the end of the year 1758 or the beginning of 1759. But Clairaut computed the effects both of Saturn and Jupiter, and found

that the former would retard its return in the last period 100 days, and the latter 511 days; and he determined the time when the comet would come to its perihelion to be April 15, 1759, observing, that he might err a month, from neglecting small quantities in the computation. It passed the perihelion on March 13, within thirty-three days of the time computed. This is the first comet the period of which was foretold, and the prediction was verified. It did not, however, make any considerable appearance, by reason of the unfavourable situation of the earth, all the time its tail might otherwise have been conspicuous, the comet being then too near the sun to be seen by us. "Let us remark," says Laplace, "for the honour of the human understanding, that this comet, which in this century only excited the curiosity of astronomers and mathematicians, had been regarded in a very different manner, four revolutions before, when it appeared in 1456. Its long tail spread consternation over all Europe, already terrified by the rapid success of the Turkish arms, which had just destroyed the great empire. Pope Callixtus, on this occasion, ordered a prayer, in which both the comet and the Turks were included in one anathema!"

Five hundred comets are supposed to have appeared since the commencement of the Christian era. Of these probably a considerable number are the different appearances of the same comet; but our knowledge of these bodies is so much in its infancy, the period of accurate observations has so lately commenced, that we have as yet but slender means of determining any question respecting them.

Of the Fixed Stars.

When we have separated the planets and comets from our consideration, we find that all the other bodies of the sphere constantly preserve the same situation with respect to each other; for this reason they are called *fixed stars*. They obviously differ again from the planets, by the twinkling of their light, however clear the atmosphere; to the unphilosophic eye they appear to be innumerable, but this is only in consequence of their being scattered over the expanse of heaven apparently without order, and our not being able to see them all at once. Of this deception of sight, we may soon convince ourselves, by selecting any particular portion of the heavens, and counting the stars it contains; the number of which will be found very small. The whole number of stars which can be seen at once by the naked eye, is not above 500; but soon after the invention of the telescope, the number actually noted down in catalogues amounted to 3000. The further telescopes have

been improved, the more have been discovered, and Dr. Herschel has, in our own time, added at least 30,000 to those formerly known.

Before we venture upon any speculations with respect to the nature of the fixed stars, it will be proper to obtain, if possible, some idea of their distances. For this purpose, we must remind the reader of the nature of a parallax, which signifies the angle subtended by the visual rays coming from an object viewed at two different situations. The moon, it has been shewn at page 522, is so near us, that its distance may be ascertained tolerably well by a horizontal parallax, which is equivalent to viewing it from two situations separated by the semi-diameter of the earth, or nearly 4000 miles. But the distance of the sun is found to be so great, that a horizontal parallax will not give a satisfactory result; philosophers therefore, it has been shewn, turned their attention, for ascertaining the distance of this luminary, to the transits of Venus, by which nearly the whole diameter of the earth formed a parallax, and enabled them to solve the problem. Two stations, however, separated by the whole diameter of the earth, are utterly incapable of shewing us the distance of a fixed star. What resource then has human ingenuity left? One which might surely be thought sufficient, that of viewing and taking the parallax of these bodies from two opposite parts of the earth's orbit. This is called the *great parallax*, or *annual parallax*. By means of the zenith sector, Hook, Flamsteed, and Bradley observed, for some time, at the spring and autumnal equinox, the transit of γ Draconis over this perpendicular telescope, hoping that the diameter of the earth's orbit might make an angle or parallax with it. They were disappointed. The star was seen so near the same place, at each of the earth's two stations, which are nearly 200 millions of miles distant from each other, that no estimate could be made! Bradley guessed there might be an angle of about two seconds, which would make the star 400,000 times further from us than the sun. Cassini supposed the annual parallax of Sirius, which of all the fixed stars is considered the nearest, to be six seconds, from which it was calculated to be 18,000 times further from us than the sun. Nothing, however, on this subject, has been determined with certainty, except the simple but truly astonishing truth, that the space of 200 millions of miles is an insensible point, when compared with the distance of the nearest fixed star.

The next telescopic peculiarity which we must notice, is, that the fixed stars have no commensurable magnitude. This is the more remarkable, as they differ from each other so much in brilliancy; but when examined with a telescope, however

great the magnifying power, the most sparkling appear only to be lucid points, intensely bright, indeed, but indivisible. Their twinkling is occasioned by the motion of particles in our atmosphere, intercepting their light; and their sensible magnitude to the naked eye arises from adventitious rays, cut off by the telescope.

From the two circumstances which have been just mentioned, to wit, the indefinite distances and magnitudes of the fixed stars, we may justly infer, that they shine by native light, otherwise they would be invisible to the naked eye: for the satellites of Jupiter and Saturn, though we can measure their distances, and they also appear of a very distinguishable magnitude through a telescope, reflect too little light to be visible without that instrument. We may calculate the distance at which 200 millions of miles would appear to our sight as a point; and supposing we assume that distance to be the distance of the nearest fixed star, we shall be satisfied, that our sun, if equally far off, would only appear like a star. Are we not then compelled to draw the conclusions, that every fixed star is itself a sun; that each of them is the centre of a system of planetary worlds; that it directs their motions, and supplies them with light and heat, in the same manner that the sun governs the several bodies of which our solar system is composed; that these planets of other systems, are furnished like ours with satellites, though these as well as their primaries are altogether invisible to us; and finally, that the fixed stars are, generally speaking, as distant from each other as the nearest of them is from the earth.

The difference of the apparent magnitudes of the fixed stars is very great; yet it is found to answer sufficiently well the purposes of description and discrimination, to distinguish them into six orders, calling the largest of them *stars of the first magnitude;* the next, *stars of the second magnitude,* and so on. The stars of the sixth magnitude are those which can barely be distinguished by the naked eye. Those which can only be seen by the help of the telescope, are usually called *telescopic stars.*

A better method than the above of distinguishing the brightness and magnitude of the stars, is that adopted by Dr. Herschel, in his catalogues of the comparative brightness of the fixed stars. It consists in referring a given star to two other stars, one of which is somewhat brighter, and the other rather less bright, than the one to be designated. "I place," says he, "each star, instead of giving its magnitude, into a short series, constructed upon the order of brightness of the nearest proper stars. For instance, to express the lustre of D, I say

CDE. By this short notation, instead of referring the star D to an imaginary, uncertain standard, I refer it to a precise and determinate existing one. C is a star that has a greater lustre than D; and E is another of less brightness than D. Both C and E are neighbouring stars, chosen in such a manner that I may see them at the same time with D, and therefore may be able to compare them properly. The lustre of C is in the same manner ascertained by BCD; that of B by ABC; and also the brightness of E by DEF; and that of F by EFG."

Astronomers divide the heavens into three regions; a northern and a southern hemisphere, and the zodiac. Stars of various magnitudes are seen in all these regions, and are classed into what are called constellations, or systems of stars, according as they lie near one another, so as to occupy those spaces which the figures of different sorts of animals, &c. would take up, if they were delineated on what appears to be the concave surface of the heavens. Those stars which the ancients could not bring into any particular constellation, they called *unformed stars*, but most of these are comprehended in the new constellations of the moderns.

This division of the stars into different constellations, or asterims, serves to distinguish them in such a manner, that any particular star may be readily found in the heavens, by means of a celestial globe, on which the constellations are so delineated as to put the most remarkable stars into those parts of the figures which may be most easily pointed out. A great improvement of this ancient mode of pointing out the stars, consists in annexing a Greek or a Roman letter, or a number, to each star, the brightest star having the first letter in the alphabet, or the lowest number, and the rest following in regular order. By these means, every star may be pointed out with as much ease, as if it had a distinct name. Thus if we see α in Orion, and α in the Twins, the former is called Alpha Orionis, and the latter Alpha Geminorum, &c. But before this arrangement prevailed, remarkable stars in some of the constellations obtained a particular name, which they still retain, as Aldebaran, Castor and Pollux, &c.

To the following list of the constellations, and of the number of stars observed in each of them, as far as those of the sixth magnitude, is subjoined the names and magnitudes of those stars to which independent names have been given:

Constellations of the Zodiac

Constellations.		No. of Stars.	Principal Stars and their Magnitudes.	
Aries	The Ram	66		
Taurus	The Bull	140	Aldebaran	1
Gemini	The Twins	85	Castor and Pollux	1.2
Cancer	The Crab	83		
Leo	The Lion	95	Regulus	1
Virgo	The Virgin	110	Spica Virginis	1
Libra	The Scales	51	Zubenisch Mali	2
Scorpio	The Scorpion	44	Antares	1
Sagittarius	The Archer	69		
Capricornus	The Goat	51		
Aquarius	The Water-carrier	108	Scheat	3
Pisces	The Fishes	112		

Constellations on the North Side of the Zodiac.

Constellations.		No. of Stars.	Principal Stars and their Magnitudes.	
Ursa Minor	The Little Bear	24	Stella Poloris	2
Ursa Major	The Great Bear	87	Dubhe	1
Cassiopeia	Lady in her Chair	55		
Perseus	Perseus	59	Algenib	2
Auriga	The Waggoner	56	Capella	1
Boötes	The Bear Driver	54	Arcturus	1
Draco	The Dragon	60	Rastaber	3
Cepheus	....	35	Alderamin	3
Canes Venatici, viz. Asterian and Chara	The Greyhounds	25		
Corona Caroli	Charles' Crown	3		
Triangulum	The Triangle	16		
Triangulum Minus	The Lesser Triangle	5		
Musca	The Bee	6		
Lynx	....	44		
Leo Minor	The Little Lion	24		
Coma Berenicis	Berenice's Hair	40		
Camelopardalus	The Camelopard	58		
Mons Menelaus	....	11		
Corona Borealis	Northern Crown	21		
Serpens	The Serpent	50		
Scutum Sobieski	Sobieski's Shield	8		

Constellations on the North Side of the Zodiac (continued.)

Constellations.		No. of Stars.	Principal Stars and their Magnitudes.	
Herculus, cum Ramo et Cerbero	Hercules kneeling	113	Ras Algiatha	3
Serpentarius sive Ophiuchus	Serpentarius......	67	Ras Alhagus	3
Taurus Poniatowski..	....	7		
Lyra...............	The Harp........	22	Vega	1
Vulpecula et Anser..	The Fox and Goose	37		
Sagitta	The Arrow	18		
Aquila	The Eagle	40	Altair..........	1
Delphinus	The Dolphin	18		
Cygnus	The Swan........	73	Deneb Adige	1
Equuleus	The Horse's Head..	10		
Lacerta	The Lizard	16		
Pegasus	The Flying Horse	85	Markab	2
Andromeda	....	66	Almaac.........	2

Constellations on the South Side of the Zodiac.

Constellations.		No. of Stars.	Principal Stars and their Magnitudes.	
Phœnix	Phenix	13		
Officina sculptoria ..	....	12		
Eridanus	The River........	76	Achernar........	1
Hydrus	The Hydra	10		
Cetus	The Whale	80	Menekar	2
Fornax Chemica	....	14		
Horologium	....	12		
Reticulus Rhomboidalis	....	10		
Xiphias	The Sword-fish....	7		
Celapraxitellis	....	16		
Lepus	The Hare........	19		
Columba Noachi	Noah's Dove	10		
Orion	....	78	Betelguese	1
Argo Navis	The Ship	50	Canopus........	1
Canis Major........	The Great Dog....	30	Sirius	1
Equuleus Pictorius ..	....	8		
Monoceros	The Unicorn......	31		
Canis Minor........	The Little Dog....	14	Procyon	1
Chamæleon	Chameleon	10		
Pixis Nautica	....	4		
Piscis Volans	The Flying Fish ..	8		

Constellations on the South Side of the Zodiac (continued.)

Constellations.		No. of Stars.	Principal stars and their Magnitudes.	
Hydra	....	60	Cor Hydræ	1
Sextans	The Sextant	4		
Robur Carolinum	The Royal Oak	12		
Machina Pneumatica	....	3		
Crater	The Cup	11	Alkes	3
Corvus	The Crow	9	Algorab	3
Crux	The Cross	6	Crucis	1
Muca	The Bee	4		
Apus	The Bird of Paradise	11		
Circinus	....	4		
Centaurus	The Centaur	36		
Lupus	The Wolf	24		
Quadra Euclidis	....	12		
Triangulum Australe	Southern Triangle	5		
Ara	The Altar	9		
Telescopium	The Telescope	9		
Corona Australis	Southern Crown	12		
Pavo	The Peacock	14		
Indus	The Indian	12		
Microscopium	The Microscope	10		
Octans Hadleianus	Hadley's Quadrant	43		
Grus	The Crane	14		
Toucan	American Goose	9		
Piscis Australis	The Southern Fish	20	Tomalhaut	1

The whole number of stars reckoned in the preceding lists, amounts to 8192, but the number which may be discerned with the assistance of telescopes is incalculable. Dr. Hook, with a telescope of twelve feet, saw 78 stars among the Pleiades; and with a longer telescope still more; and in the constellation Orion, which is usually reckoned to contain 78 stars, there have been seen 2000. Dr. Herschel, with a telescope that magnifies from five to six thousand times, has counted forty-four thousand in a space of sky eight degrees in length, and three in width; and supposing this quantity to be the same in all portions of the sky, of equal dimensions, the whole number of stars, that may be rendered visible by such a telescope, cannot be fewer than seventy-four millions.

Kepler has made a very ingenious observation upon the magnitudes and distances of the fixed stars. He observes, that there can be only thirteen points upon the surface of a sphere, as far distant from each other as from the centre, and supposing

the nearest fixed stars to be as far distant from each other as from the sun, he concludes that there can, strictly speaking, be only 13 stars of the first magnitude. Hence at twice that distance from the sun there may be placed four times as many, and so on; and this mode of calculation gives us pretty nearly the number of stars of the first, second, third, &c. magnitudes.

It is a fact no less singular than well ascertained, that stars which were observed by the ancients are now no longer to be seen, and new ones have appeared in different places, which were unknown to the ancients, and some of these have also disappeared and again become visible. Hipparchus, the ancient astronomer, having observed the disappearance of a star, was induced to make a catalogue of the fixed stars, that posterity might judge whether any other change took place among them. Many ages afterwards, a new star having been observed by Tycho Brahe and his contemporaries, this astronomer also determined to make a catalogue with the same view as Hipparchus. Of the new star seen by Brahe, and on the subject of changes among the stars in general, we have the following interesting account by Dr Halley: "The first new star in the Chair of Cassiopeia was not seen by Cornelius Gemma on the 8th of November 1572, who says, he that night considered that part of the heaven in a very serene sky, and saw it not; but that the next night, November 9, it appeared, with a splendour surpassing all the fixed stars, and scarcely less bright than Venus. This was not seen by Tycho Brahe before the 11th of the same month; but from thence he assures us that it gradually decreased and died away; so as in March, 1574, after 16 months, to be no longer visible; and at this day no signs of it remain. Its place in the sphere of fixed stars, by the accurate observations of the same Tycho, was 0^s $9°$ $17'$ a 1^{ma}*♈, with $53°$ $45'$ north latitude. Such another star was seen and observed by the scholars of Kepler, to begin to appear on September 30, St. Vet. anno 1604, which was not to be seen the day before; but it broke out at once with a lustre surpassing that of Jupiter; and like the former, it died away gradually, and in much about the same time disappeared totally, there remaining no footsteps thereof in January, 1605-6. This was near the ecliptic, following the right leg of Serpentarius; and by the observations of Kepler and others, was in 7^s $28°$ $0'$ a 1^{ma}*♈, with north latitude $1°$ $56'$. These two seem to be of a distinct species from the rest, and nothing like them has appeared since. But between them, viz. in the year 1596, we have the first account of the wonderful star in Collo Ceti, seen by David Fabricius on the 14th of August, as bright as a star of the third magnitude, which has been since found to appear

and disappear periodically; its period being precisely enough seven revolutions in six years, though it returns not always with the same lustre. Nor is it ever totally extinguished, but may at all times be seen with a six feet tube, [telescope.] This was singular in its kind, till that in Collo Cigni was discovered. It precedes the first star of Aries $1^\circ\ 40'$, with $15^\circ\ 57'$ south latitude. Another new star was first discovered by William Jansonius, in the year 1600, in Pectore, or rather in Eductione Colli Cygni, which exceeded not the third magnitude. This having continued some years, became at length so small, as to be thought by some to have disappeared entirely; but in the years 1657, 1658, and 1659, it again arose to the third magnitude; though soon after it decayed by degrees to the fifth or sixth magnitude, and at this day is to be been as such in $9^s\ 18^\circ\ 38'$ a 1^{ma}*♈, with $55^\circ\ 29'$ north latitude. A fifth new star was first seen by Hevelius in the year 1670, on July 15, St. Vet. as a star of the third magnitude; but by the beginning of October was scarcely to be perceived by the naked eye. In April following, it was again as bright as before, or rather greater than of the third magnitude, yet wholly disappeared about the middle of August. The next year, in March 1672, it was seen again, but not exceeding the sixth magnitude: since when, it has been no further visible, though we have frequently sought for its return; its place is $9^s\ 3^\circ\ 17'$ a 1^{ma}*♈, and has lat. north $47^\circ\ 28'$. The sixth and last is that discovered by G. Kirch in the year 1686, and its period determined to be of $404\frac{1}{2}$ days, and though it rarely exceeds the 5th magnitude, yet it is very regular in its returns, as we found in the year 1714. Since then we have watched, as the absence of the moon and the clearness of the weather would permit, the first beginning of its appearance in a six-feet tube, that, bearing a very great aperture, discovers most minute stars. And on June 15th last, it was first perceived like one of the first telescopical stars; but in the rest of that month and July, it gradually increased, so as to become in August visible to the naked eye, and so continued till the month of September. After that it again died away by degrees; and on the 8th of December, at night, was scarcely discernible by the tube; and as near as could be guessed, equal to what it was at its first appearance on June 15, so that this year it has been seen in all nearly six months, which is but little less than half its period; and the middle, and consequently the greatest brightness, falls about the 10th of September."

In the 76th volume of the Philosophical Transactions, a paper, by Edward Pigot, gives a dissertation on the stars sus-

pected by the astronomers of the last century to be changeable. The author divides them into two classes; one containing those which are undoubtedly changeable, and the other those which are only suspected to be so. The first class contains a list of 12 stars from the first to the fourth magnitude, including the new one which appeared in Cassiopeia, in 1572, and that in Serpentarius in 1604: the second contains the names of 30 stars of different magnitudes, from the first to the seventh. He is of opinion, that the celebrated new star in Cassiopeia is a periodical one, and that it returns once in 150 years. Keill is of the same opinion; and Pigot thinks that its not being observed at the expiration of each period, is no argument against the truth of that opinion, remarking, that, "like most of the variables, it may at different periods have different degrees of lustre, so as sometimes only to increase to the ninth magnitude; and if this should be the case, its period is probably much shorter." For this reason, in September, 1782, he took a plan of the small stars near the place where it formerly appeared, but in four years had observed no alteration. He also examined the star in the neck of the Whale, from the end of 1782, to 1786, but he never found it exceed the sixth magnitude, though it had been observed by others at different times to be of the third magnitude. He deduced its period, from its apparent equality with a smaller star in the neighbourhood, and thence found it to be 320, 328, and 337 days. Another changeable star, and one of the most remarkable of the class, is that called Algol, in the head of Medusa; it had long been known to be variable, but its period was first ascertained by Goodricke, of York, who began to observe it in the beginning of 1783. It seems to have a period of about 2 days, 21 hours, during which it varies gradually from the size of the second to that of the fourth magnitude in about 3½ hours; after which time it gradually recovers its greatest lustre, which it preserves to the end of its period, and then again begins to diminish.

These changes among the fixed stars have given rise to a great variety of hypotheses to account for them. The suggestion of Sir Issac Newton, that the transitory blaze of some of them, might be owing to the addition of fuel they have received from the influx of a comet, has already been noticed. Maupertuis thought some stars, by their prodigiously quick rotations on their axis, may not only assume the figures of oblate spheroids, but that, from the great centrifugal force arising from such rotations, they may become of the figures of mill-stones; or be reduced to flat circular planes, so thin as to be quite invisible when their edges are turned towards

us, as Saturn's ring is in such positions. But when very eccentric planets or comets go round any flat star, in orbits much inclined to its equator, the attraction of the planets or comets in their perihelions, must alter the inclination of the axis of that star; on which account, it will appear more or less large and luminous, as its broad side is more or less turned towards us. A third opinion is, that the changes in question may be owing to spots on the surfaces of the stars, so that when, by their periodical rotations on their axis, these spots are turned towards us, the star is either not seen at all, or appears less bright than at other times. Lastly, it is conjectured that they revolve in very considerable orbits, and that we only see them when they are nearest to us. It probably is not one uniform cause that occasions the phenomena, which may be owing sometimes to one and sometimes to another of the causes assigned, or to various others of which we have not the least apprehension; indeed, ages of assiduous observation may elapse before any rational conjecture can be offered on the subject.

On almost any evening which is clear enough for the stars to be seen with tolerable distinctness, we may observe in the heavens, a broad tract, of a whitish colour. This remarkable tract is called, from its whiteness, the *galaxy*, *via lactea*, or *milky way*. On more minute inspection, we may observe a number of separate whitish places, affording the same kind of light as the milky way, but not so bright; these are called *nebulæ*.

The milky way encircles the celestial concave; it is irregularly extended, sometimes double, but for the most part single, and varies in breadth from 4° to 20°. It passes through Cassiopeia, Perseus, Auriga, the foot of Gemini, Orion's club, part of Monoceros, the tail of Canis Major, through Argo Navis, Robur Carolinum, Crux, and the feet of the Centaur; here it divides into two parts; its eastern branch passes through Ara, the tail of Scorpio, the eastern foot of Serpentarius, the bow of Sagittarius, Scutum Sobiescianum, the feet of Antinous, and Cygnus. Its western branch passes through the upper part of the tail of Scorpio, the right of Serpentarius and Cygnus, and ends in Cassiopeia. With a powerful telescope, Dr. Herschel first began to survey the via lactea, and found that it completely resolved the whitish appearance into stars which the telescope he formerly used had not power enough to do. The portion he first observed, was that about the hand and club of Orion; he perceived in it an astonishing multitude of stars, the number of which he endeavoured to estimate, by counting many different telescopic fields of view, and computing from a

mean of these how many might be contained in a given portion of the milky way. In the most vacant place to be met with in that neighbourhood, he found 63 stars; other six fields contained 110, 60, 70, 90, 70, and 74 stars; a mean of all which gave 76 for the number of stars to each field; and thus he found, that by allowing fifteen minutes for the diameter of his field of view, a belt of 15 degrees long, and two broad, which he had often seen pass before his telescope in an hour's time, could not contain less than 50,000 stars, large enough to be distinctly numbered; besides which, he suspected twice as many more, which could be seen only now and then by faint glimpses, for want of sufficient light.

Dr. Herschel's success in examining the milky way, induced him to turn his telescope to the nebulous parts of the heavens. Most of these yielded to a Newtonian reflector, of 20 feet focal distance, and 12 inches aperture; which plainly discovered them to be composed of stars, or at least to contain stars, and to afford very strong indications of their consisting of them entirely. "The nebulæ," says he, "are arranged into strata, and run on to a great length, and some of them I have been able to pursue, and to guess pretty well at their form and direction. It is probable enough that they may surround the whole starry sphere of the heavens, not unlike the milky way, which undoubtedly is nothing but a stratum of fixed stars; and as this immense starry bed is not of equal lustre in every part, nor runs on in one straight direction, but is curved, and even divided into two streams along a very considerable portion of it; we may likewise expect the greatest variety in the strata of the cluster of the stars and nebulæ. One of these nebulous beds is so rich, that, in passing through a section of it in the time of only 36 minutes, I have detected no less than 31 nebulæ, all distinctly visible upon a fine blue sky. Their situation and shape, as well as condition, seem to denote the greatest variety imaginable. In another stratum, or perhaps a different branch of the former, I have often seen double and treble nebulæ variously arranged; large ones, with small seeming attendants; narrow, but much extended lucid nebulæ or bright dashes; some of the shape of a fan, resembling an electric brush issuing from a lucid point; others of the cometic shape, with a seeming nucleus in the centre, or like cloudy stars, surrounded with a nebulous atmosphere: a different sort of orb again, contain a nebulosity of the milky kind, like that wonderful, inexplicable phenomena about Orionis; while others shine with a fainter mottled kind of light, which denotes their being resolvable into stars.

"It is very probable that the great stratum called the milky

way, is that in which the sun is placed, though perhaps not in the very centre of its thickness. We gather this from the appearance of the galaxy, which seems to encompass the whole heavens, as it certainly must do if the sun is within the same: for, suppose a number of stars arranged between two parallel planes, indefinitely extended every way, but at a given considerable distance from one another, and calling this a sidereal stratum, an eye placed somewhere within it, will see all the stars in the direction of the planes of the stratum projected into a great circle, which will appear lucid, on account of the accumulation of the stars, while the rest of the heavens, at the sides, will only seem to be scattered over with constellations, more or less crowded, according to the distance of the planes, or number of stars contained in the thickness or sides of the stratum."

The nebulæ have been divided into three kind . The first kind comprises those which consist of a great number of stars crowded together, and which are seen to be distinct through a telescope. Among these, is the famous nebulæ of Cancer, or the *præsepe cancri*, forming a collection of 25 or 30 stars, and many similar groups in various parts of the heavens.—The second kind consist of one or more stars, surrounded by a whitish spot, through which they seem to shine. There are several of this sort, but one of the most remarkable is that in Orion, which, through a telescope, appears as a whitish spot nearly triangular: it contains seven stars, one of which is itself surrounded by a small cloud brighter than the rest of the spot.—Nebulæ of the third kind are white spots in which no stars are seen when viewed with a telescope.—Fourteen of these have been observed in the austral hemisphere, among which the celebrated spots, near the south pole, called by sailors the Magellanic clouds, hold the first rank.—Dr. Herschel has given catalogues of 2000 nebulæ and clusters of stars discovered by himself.

We will now, says the Doctor, in one of his papers on this subject, retreat to our own retired situation in one of the planets, attending a star in the great combination, with numberless others; and in order to investigate what will be the appearances from this contracted situation, let us begin with the naked eye. The stars of the first magnitude being in all probability the nearest, will furnish us with a step to begin our scale; setting off therefore with the distance of Sirius, or Arcturus, for instance, as unity, we will at present suppose, that those of the second magnitude are at double, and those of the third at treble the distance, and so forth. Taking it

then for granted, that a star of the seventh magnitude is about seven times as far from us as one of the first, it follows that an observer, who is enclosed in a globular cluster of stars, and not far from the centre, will never be able, with the naked eye, to see the end of it: for since, according to the above estimations, he can only extend his view about seven times the distance of Sirius, it cannot be expected that his eyes should reach the borders of a cluster, which has perhaps fifty stars in depth every where around him. The whole universe, therefore, to him, will be comprised in a set of constellations, richly ornamented with scattered stars of all sizes. Or if the united brightness of a neighbouring cluster of stars should, in a remarkably clear night, reach his sight, it will put on the appearance of a small, faint, nebulous cloud, not to be perceived without the greatest attention. Allowing him the use of a common telescope, he begins to suspect that all the milkiness of the bright path which surrounds the sphere may be owing to stars. By increasing his power of vision, he becomes certain that the milky way is, indeed, no other than a collection of very small stars, and the nebulæ nothing but clusters of stars.

Dr. Herschel then solves a general problem for computing the length of the visual ray: that of the telescope which he uses, will reach to stars 497 times the distance of Sirius. Now according to his reasoning, Sirius cannot be nearer than 100,000 × 194,000,000 of miles, therefore his telescope will, at least, reach to 100,000 × 194,000,000 × 497 miles. And he observes, that in the most crowded part of the milky way, he has had fields of view that contained no less than 588 stars, and these were continued for many minutes; so that, in a quarter of an hour, he has seen 116,000 stars pass through the field of view of a telescope of only 15′ aperture; and at another time in 41 minutes he saw 258,000 stars pass through the field of his telescope. Every improvement in his telescopes has discovered stars not seen before, so that there appears no bounds to their number, or to the extent of the universe.

The sun, like many other stars, has probably a progressive motion directed towards the constellation Hercules, carrying all its attendant planets along with it; and with respect to this motion, Dr. Herschel observes, that the apparent proper motions of 44 stars out of 56, are nearly in the direction which would be the result of such a real motion of the solar system; and that the bright stars Arcturus and Sirius, which are probably the nearest to us, have, as they ought, according to this theory, the greatest apparent motions. Again, the star Castor,

appears when viewed with a telescope, to consist of two stars, of nearly equal magnitude; and though they have an apparent motion, they have never been found to change their distance with respect to one another a single second, a circumstance easily understood, if both their apparent motions are supposed to arise from the real motion of the sun.



In the infancy of science, when the distances of the sun and planets were unknown, man, unable to draw any just conclusion respecting objects so much beyond his reach, never doubted that he was the only being of his kind in the universe, or that the earth was the most consequential aggregate of matter in existence. It was not without many a struggle, and by slow degrees, that he withdrew from the dominion of so contemptible a belief. At length, when the evidence, continually accumulating, triumphed over all contradiction; when the magnificence of the planetary orbs became perfectly evident; when it was proved that they certainly experienced the regular return of day and night, spring, summer, autumn, and winter; it became difficult to deny the plurality of inhabited worlds, with any hope of rationally explaining the design of that exertion of Creative Power which called those orbs into existence, and subjected them to the same laws as the earth; and man was constrained to admit, that a grain of sand was not more completely an atom to the earth, than the earth itself was an atom to the solar system. These ideas had scarcely obtained general acceptance, when it was found that the distances of all the fixed stars is immeasurably great; then it became obvious that they shine by their own light; that they are each of them comparable in real splendour and magnitude to the sun; that they are as distant from each other as any one of them must be from us; that therefore, instead of being merely as ornaments of the sky, the most reasonable conclusions of analogy inculcated, that they were the centres of so many systems, dispersed throughout the universe, and dispensing light and heat to planetary worlds around them; and the use of the telescope, at the same time that it imparted the power of counting millions of stars which the naked eye never beheld, yielded a convincing evidence, that millions of millions exist, at distances too great to be separately distinguished. From the insignificance of the earth compared with the whole solar system, man now advanced to the perception of the insignificance of the whole solar system, compared with the remaining immensity of

creation; so that the total annihilation of the system that appears so vast to him, would be like the abstraction of nothing from the universe. On the wings of conjecture, indeed, but still with analogy by our side, we may take a still more eminent if not expansive view. If there are reasons to believe that every orb of the solar system is inhabited, there are reasons scarcely less strong for believing that every star, and every orb attending every star, is created and exists only for the same great purpose. What incommunicable feelings do these views excite! Perhaps all the stars that we can discover, and all, of the existence of which we can obtain any evidence, form a very finite part of the total number; yet, is it possible by any other means, to obtain so admirable a view of Infinite Power and Infinite Wisdom, as may be derived from the contemplation of the attributes of that Being who has created, and maintains, even that portion which we can actually discern of the stupendous fabric of Universal Nature?

Of the Tides.

Having now ranged over the mighty field of astronomical research, we must next proceed to consider a variety of phenomena, resulting from the general laws of nature, which are particularly and immediately interesting to us as inhabitants of the earth, but which would have too much interrupted our general view, if we had entered sufficiently into the details of them in the course of our progress. Here then we shall in the first place advert to those remarkable fluctuations of the ocean called *Tides*.

The apparent connection subsisting between the movements of the ocean and those of the moon, has been observed from the earliest periods of antiquity; but it was Kepler who first asserted that the moon's attraction was the real cause; "If," says he, "the earth ceased to attract its waters towards itself, all the water in the ocean would rise and flow to the moon. The sphere of the moon's attraction extends to our earth, and draws up the water." Sir Isaac Newton afterwards demonstrated the consonance of the cause assigned by Kepler, with his theory of universal gravitation, and explained at the same time the cause of the tides on the side of the earth opposite to the moon, and from his time to the present, not a doubt has been entertained on the subject.

The principal phenomena of the tides are as follows:

1. The sea is observed to flow for about six hours from south to north, gradually swelling; after this it seems to rest for a quarter of an hour; and then to ebb or retire back again

from north to south, for six hours more. Then after another pause of about a quarter of an hour, the sea again begins to flow; and so on alternately.

2. The time of a flux and reflux, is on an average about 12 hours 25 minutes, and twice this time, or 24 hours 50 minutes, is the period of a lunar day, or the time between the moon's passing a meridian, and coming to the same point of it again. So that the sea flows as often as the moon passes the meridian, that is, as well when she comes to the arch above the horizon, as when she comes to that below the horizon; and ebbs as often as the moon passes the horizon, both on the eastern and western side.

3. The elevation of the waters on that side of the earth immediately under the moon, somewhat exceeds the elevation of the opposite side, and in all cases the elevation diminishes from the equator to the poles.

4. The sun raises and depresses the sea twice every day, in the same manner as the moon; but the solar influence in this respect is less than that of the moon, in the proportion of 1 to 3.

5. The tides which depend on the actions of the sun and moon, are not distinguished but compounded; and thus they form, to appearance, one united tide, which increasing and decreasing, produces Neap and Spring tides.

6. In the syzygies, that is, when the moon is either new or full, the action of both luminaries concur, and the tides are highest; but they are least in the quadratures, or when the lines of their action are 90 degrees apart, for where the water is elevated by the moon, it is depressed by the sun, and *vice versâ.* Therefore while the moon passes from the syzygy to the quadrature, the daily elevations are continually diminished: on the contrary, they are increased, while the moon passes from the quadrature to the syzygy. At the new moon, also, the tides are the greatest, because the sun and moon are not only in the same line, but on the same side of the earth; and at this time the tides of the same day are more different than those at full moon.

7. The greatest elevations and depressions take place on the second or third day after the new or full moon; and they are the greater the nearer the luminaries are to the plane of the equator; they are therefore greatest in the syzygies at the time of the equinoxes.

8. The actions of the sun and moon are greater, the nearer these bodies are to the earth; and the greatest tides happen when the sun is a little to the south of the equator; but this does not happen regularly every year, because some variation

may arise from the situation of the moon's orbit, and the distance of the syzygy from the equinox.

9. As the mean force of the moon to move the sea, is to that of the sun nearly as 3 to 1; if the action of the sun alone would produce a tide of two feet, which it is said to do, then that of the moon will be six feet; hence the spring-tides will be eight feet, and the neap tides four feet.

These phenomena take place where the ocean is sufficiently extended to admit of those motions which the actions of the sun and moon have a tendency to impart; but they are variously modified by the obstacles which the water meets with in its course; from the direction of the wind; from straits and gulfs; from capes, bays, and other peculiarities of the shores of different countries; so that on some shores, little or no tide is observed, and on others they rise far beyond the amount determined, without taking into consideration the modifying circumstances.

The tides are propagated to great distances in large rivers; and at the strait of Pauxis, in the river of the Amazons, they are sensible at 600 miles from the sea.

In explaining the general principles on which the tides depend, it must be observed and remembered, that if the action of the moon were *equal* upon every part of the ocean, we should have no tides; it is the *inequality* of its action that produces them. The action of the moon is greatest in the direction of a line that would join its centre of gravity with that of the earth; to this line as an axis, the ocean rushes up from every side, and as this line moves, the water which flowed up to it at the first moment of the moon's action, continues to move along with it. The inequality of the moon's action is not so great as to counteract the cohesion which the solid parts of the earth have to each other, and therefore they are unaffected by it; but the particles of fluids move among each other with such facility, that they receive it readily. To understand more fully why the moon exerts an unequal action on the earth, it is necessary to recollect that the power of gravity diminishes as the square of the distance increases; and therefore the waters of the earth ABCDEFGH, fig. 1, pl. IV, must be more attracted at Z, on the side next the moon, M, than at the central parts of the earth, O; and the central parts are more attracted by the same power than the waters on the opposite side of the earth at N; and therefore the distance from the earth's centre, and the waters on its surface under and opposite to the moon, will be increased. For, let there be three bodies at H, O, and D; if they are all equally attracted by the body at M, they will all move equally fast towards it, their mutual distances

from each other continuing the same. If the attraction of M is unequal, then that body which is most strongly attracted will move fastest, and this will increase its distance from the other body. Therefore, by the law of gravitation, M will attract H more strongly than it will attract O, by which the distance between H and O will be increased; and a spectator at O will perceive H rising higher towards Z. In like manner, O being more strongly attracted than D, it will move faster towards M than D; consequently the distance between O and D will be increased; and a spectator at O, not perceiving his own motion, will see D receding farther from him towards N; all effects and appearances being the same, whether D recedes from O, or O from D.

Suppose now there are a number of bodies, as A, B, C, D, E, F, G, H, or in one word, a fluid ring, placed about O; then as the whole is attracted towards M, the parts at H and D will have their distance from O increased; whilst the parts at B and F, being nearly at the same distance as O from M, will not recede from one another; but rather, by the oblique attraction of M, they will approach nearer to O. The fluid ring therefore will form itself into an ellipse ZIBLNKFRZ, whose longer axis, NOZ, it produced, will pass through M, and its shorter axis BOF, will terminate in B and F. Let the ring be filled with fluid particles, so as to form a sphere round O; then as the whole moves towards M, the fluid sphere being lengthened at Z and N, will assume an oblong or spheroidal form. If M is the moon, O the earth's centre, ABCDEFGH the sea covering the earth's surface, it is evident, by the above reasoning, that whilst the earth, by its gravity, falls towards the moon, the water directly below the moon at B, will swell and rise gradually towards her; also the water at D will recede from the centre, and rise on the opposite side of the earth, whilst the water at B and F is depressed, and falls below the former level. Hence as the earth turns round its axis from the moon to the moon again in 24 hours 50′, there will be two tides of flood, and two of ebb, in that time. By the motion of the earth on its axis, the most elevated part of the water is carried beyond the moon, in the direction of the rotation; but the water, from the accumulation of impulse, still continues to rise after it has passed directly under the the moon, though the greatest immediate action of the moon has then begun to decrease. The greatest elevation is not attained, till the moon has for the space of an hour or more ceased to be vertical to the place where it occurs. Thus, in open seas, where the water flows freely, the moon M is past the north and south meridian, as at *p*, when it is high water

at Z and N. For it will be understood, that though the moon's attraction were to cease altogether when she was past the meridian, yet the motion of ascent previously communicated to the water, would make it continue to rise for some time after; much more must it do so when the attraction is only diminished; this is agreeable to the ordinary phenomenon that the heat is greater at two in the afternoon, than when the sun is on the meridian. The tides do not always answer to the same distance of the moon from the meridian at the same places; but are variously affected by the action of the sun, which brings them on sooner when the moon is in her first and third quarters, and keeps them back when she is in her second and fourth; because, in the former case, the tides raised by the sun alone would be earlier than the tides raised by the moon; and in the latter case they would be later.

It is not difficult for the novice to admit, that the moon should have the stated effect on the waters of the hemisphere immediately beneath it; but it excites surprise, and is not so easily understood, that it should produce the like effect on the opposite hemisphere, and that it should be flood or ebb tide with our antipodes at the same time that it is flood-tide or ebb-tide with us. Here then we must remark again, that it is not the absolute or total action of the moon, but the difference between its action on one part and its action on another, that constitutes the force which occasions any tide. The point Z is nearer to the moon than any other part of the hemisphere BZF; the waters therefore about that point are more strongly attracted by the moon M, than at others more remote; and since this attraction acts in a contrary direction to that of the earth, the waters of all parts from BF to Z must have their gravity or tendency towards the centre, O, diminished, and as this tendency to the centre is the least at the point Z, they will consequently stand higher there than in any other part of the hemisphere. Now on the opposite hemisphere, BFN, the moon's attraction is also unequally exerted, and the necessary consequence of that unequal action produces tides. From B and F to N, the force of the moon's attraction is diminished, agreeably to the general rule, as the square of the distance increases. At N it is the least of all, and as the attraction of the waters to the centre of the earth is also the least there, because in the hemisphere BFN, the moon's attraction in proportion to the nearness of the parts to B and F, favours the earth's, the water will be higher there than at any other part of the hemisphere. Hence the moon raises the waters, both at that point of the earth which is nearest to her, and at that which is furthest from her, at the

same time. At any port or harbour, therefore, which lies open to the ocean, the action of the moon will tend to elevate the waters there, when she is on the meridian of that place, whether she be on the arch of the meridian above, or on that below the horizon. But the water cannot be raised at one place, without flowing from and being depressed at another, and these elevations and depressions will obviously be the greatest at opposite points of the earth's surface. When the moon raises the waters at Z and N, they will be depressed at B and F; and when by the earth's rotation they are raised by her at B and F, they will be depressed at Z and N. And as the moon passes over the meridian, and is in the horizon twice every day, there must therefore, as we find by experience, be two tides of flood and two of ebb in that time, at the interval of about six hours and twelve minutes.

The whole attractive force exerted by the sun on the earth, is far superior to that of the moon, but as his distance from the earth is nearly 400 times greater, the intensity of the forces with which he acts upon different parts of it, are much nearer to equality than those of the moon; and as it is the difference of intensity that is alone exerted in producing tides, his action in this respect is inferior to that of the moon. Newton calculated the effect of the sun's influence to be three times less than that of the moon. The action of the sun is therefore sufficient to produce a flux and reflux of the sea, and in fact there are two tides, a solar one and a lunar one; which have a joint or opposite effect, according to the situation of these bodies. At fig. 2, plate IV, they conspire together, on the same side as the earth, the new moon at A, and the sun at S, their centres being nearly in the same line; and they raise the water at Z and N higher than either of them could do alone. When the moon is full, as at B, directly opposite the sun, and on the opposite side of the earth, it again acts in the same line as the sun, and the effect produced on the ocean is nearly the same as before; and in both cases they occasion what are called spring tides. Now, as shewn by fig. 3, let us suppose the sun to be at S, while the moon is at Q, in her first quarter. Here the sun and moon tend to counteract each other's effect; for the one would raise the ocean highest where the other would make it least. If the forces then were equal, there would be no tide, but as that of the moon is strongest in the proportion of 3 to 1, the difference between the forces is the moon's effect, and the water is therefore raised twice as high under the moon as under the sun. When the moon has arrived at her third quarter at R, her situation relatively to the sun is the same as when she was in

her first, her force and that of the sun act in lines perpendicular to each other as before, and therefore the effect corresponds.

The effects of the sun and the moon, on the waters of the ocean, are sensibly varied by the different distances of those bodies, produced by the elliptical orbit of the earth round the sun, and of that of the moon round the earth. Sir Isaac Newton shews that their actions increase as the cubes of the distances decrease; so that the moon at half its mean distance would produce a tide eight times greater than at present. Other variations likewise take place in consequence of the different declinations of the sun and moon at different times; for if either of these luminaries were at the pole, it would occasion a constant elevation at both poles, and a constant depression at the equator Hence by the declination or departure of these bodies either northward or southward from the equator, their effect is lessened, and the tides are less. The highest tides therefore occur when both the sun and moon are in the equator, where the centrifugal force is the greatest; and the moon is not only either new or full at the same time, but also in her perigee, or at her least distance from the earth. The effect would be still greater if the sun could be nearest the earth at the same time that he is in the equator; but as this is impossible, because he is nearest to us in winter, when he is southward of the equator, therefore the spring tides are highest and the neap tides lowest about the time of the equinoxes in March and September, for at these two seasons the circumstances upon which the elevation of the waters depends, conspire to produce the greatest effect. The highest tides happen a little before the vernal equinox, when the sun is retiring from the earth; and a little after the autumnal equinox, when the sun is approaching nearer to the earth.

From the foregoing theory it follows, that when the earth's axis inclines to the moon, the northern tides, if not retarded in their passage through shoals and channels, nor affected by the winds, ought to be greatest when the moon is above the horizon, and least when she is below it; and quite the reverse when the earth's axis declines from her; but in those cases they return at equal intervals of time. When the earth's axis inclines sideways to the moon, both tides are equally high; but they happen at unequal intervals of time. In summer, the earth's axis inclines towards the moon when new; and therefore the day-tides ought to be highest, and night-tides lowest about the change: at the full, the reverse. At the quarter, they ought to be equally high, but unequal in their returns; because the earth's axis then inclines sideways to the moon. In winter, the phenomena are the same at full moon, as in summer at new. In

autumn, the earth's axis inclines sideways to the moon, when new and full; therefore the tides ought to be equally high, and unequal in their returns at these times. At the first quarter, the tides of flood should be least when the moon is above the horizon, greatest when she is below it; and the reverse at her third quarter. In spring, the phenomena of the first quarter answer to those of the third quarter in autumn; and *vice versâ*. The nearer any time is to either of these seasons, the more the tides partake of the phenomena of the nearest season; and in the middle between them, the tides are at a mean state between those of both.

The tides cannot have their full motion, unless the ocean to which the moon is vertical, be of a uniform depth, and extended from east to west, over the whole globe. They are so retarded in their passage through different shoals and channels, and otherwise so variously affected by striking against capes and headlands, that to different places they happen at all distances of the moon from the meridian; consequently at all hours of the lunar day. The tide propagated by the moon in the German ocean, when she is three hours past the meridian, takes twelve hours to come from thence to London bridge, where it arrives by the time that a new tide is raised in the ocean; and therefore when the moon has north declination, and we should expect the tide at London to be greatest when the moon is above the horizon, we find it is least; and the contrary when she has south declination. At several places it is high water three hours before the moon comes to the meridian; but the tide that appears to precede the moon, is only the tide opposite to that which was raised by her when she was nine hours past the opposite meridian.

There are no tides in lakes, because they are generally so small, that when the moon is vertical she attracts every part of them almost alike, and therefore no part of the water is raised perceptibly higher than the rest. She passes over them, likewise, so quickly, that the equilibrium of the water can at most be disturbed for a very transient space of time. The Mediterranean and Baltic seas have very small elevations, because the inlets by which they communicate with the ocean are so narrow, that they cannot, in so short a time, receive or discharge enough to raise or sink their surfaces sensibly.

Among the islands in the West Indies, the tides seldom rise higher than twelve or fourteen inches, which appears remarkable, because, from their proximity to the equator, these islands are more under the influence of the moon than some other places where the fluctuation is twenty or thirty times as

great. But it must be observed, that as the Atlantic ocean turns from the moon, from west to east, her influence on its water must be from east to west; this tide, like a prodigious wave, is stopped by America, and reflected back as the moon passes over the Pacific ocean. But in the same direction that the moon drags the waters of the Atlantic, the trade winds constantly blow; and so great is the power of wind, that tides every-where are made greater or less according as the wind is with them or against them. Now the gulf of Mexico is a cavity between North and South America, into which the winds and tides are perpetually pouring water; so that the first tide that ever flowed into it, may be said to be kept up in it by this unremitting influx, and, of course, the tides cannot rise and fall as in places less in the way of these causes. But water raised above the general level, always endeavours to fall back to that level; the trade winds in some measure prevent this, by blowing perpetually from the east. As water so accumulated, cannot return in opposition to the trade winds, it turns round the west end of Cuba, and meeting with the Bahama Islands, is turned northward along the coast of America; forming that remarkable stream, the strong current of the Gulf of Florida. To shew that this accumulation actually takes place in the Gulf of Mexico, a survey was made across the isthmus of Darien, by which it was found that the water on the Atlantic side was fourteen feet higher than the water on the Pacific side.

From the lightness of the air, its freedom of motion, and its greater nearness to the moon than the ocean, it may be supposed that there are aërial tides of great elevation; but it seems to contradict this supposition, when we find that there are no changes of the barometer indicating this to be extensively the case. A little consideration, however, will shew, that such a change of the barometer is not to be expected. By the preceding theory of the tides, it appears that water is higher immediately under the moon, and at the same time to the antipodes of the point immediately under her, that is, at those two places on the earth where her attraction is greatest and least. Now though the water is higher at these two points than elsewhere, yet it does not follow that the water, from its increased quantity, presses with a proportionately greater weight on the bottom of the ocean than before it was thus raised up, because the moon's attraction has diminished that tendency to the centre of the earth which constitutes the weight of bodies. Hence we may suppose, that though the moon draws up the atmosphere to a great height, yet a higher column of mercury is not supported

through this circumstance, because the actual weight of the atmosphere remains but little affected.

Of the Harvest Moon, and Hunter's Moon.

When the earth, in turning on its axis from west to east, has revolved from one meridian to the same meridian again, the moon, which also revolves from west to east, has advanced over little more than a thirtieth part of her orbit, or 12° and some minutes; hence the tides do not occur till after the earth has overtaken her, and therefore are generally observed and supposed to be about 50 minutes later every day. This is not, however, constantly the case, except at or near the equator; for on account of the different angles made by the horizon and different parts of the moon's orbit, this retardation differs considerably in places of high latitude. Twice in the year she rises for a week together nearly at the same time, and these phenomena happening successively in autumn, the earlier is called the *harvest moon,* and the later the *hunter's moon.* We shall chiefly be indebted to Ferguson for the explanation of these problems.

The plane of the equinoctial is perpendicular to the earth's axis; and therefore as the earth turns round its axis, all parts of the equinoctial make equal angles with the horizon, both at rising and at setting; so that equal portions of it always rise or set in equal times. Consequently, if the moon's motion were equable, and in the equinoctial, at the rate of 12° 11′ from the sun every day, as it is in her orbit, she would rise and set 50 minutes later every day than on the preceding day: for 12° 11′ of the equinoctial rise or set in 50′ of time in all latitudes. But the moon's orbit is so nearly in the same plane as the ecliptic, that we may consider her at present as moving in the ecliptic. Now the different parts of the ecliptic, on account of its obliquity to the earth's axis, make very different angles with the horizon as they rise or set. Those parts or signs which rise with the smallest angles, set with the greatest, and *vice versâ.* In equal times, whenever this angle is least, a greater portion of the ecliptic rises than when the angle is larger, as may be easily perceived by referring to a globe. Thus in fig. 4 and 5, pl. IV, L represents the latitude of London, AB the horizon to that place, FP the axis of the world, E *e* the equator, K *k* the ecliptic. On account of the oblique position of the sphere in the latitude of London, the ecliptic has a high elevation above the horizon, making the angle AVK, in fig. 4, about 62½ degrees, when the sign of Cancer is upon the meridian, at

which time Libra rises in the east. But when the other part of the ecliptic is above the horizon, that is, when the sign of Capricorn is upon the meridian, and Aries rises in the east, then the ecliptic will make with the horizon the much smaller angle *k* VA, as represented by fig. 5, which angle is only about 15 degrees, that is, 47½ degrees smaller than the former angle. Thus it may be conceived, that as the celestial sphere appears to turn round the axis FP, a greater portion of the ecliptic will rise in a given portion of time, as for instance, three or four hours, when the ecliptic is in the situation of fig. 5, than when it is in the situation of fig. 4.

In northern latitudes, the smallest angle made by the ecliptic and horizon, is when Aries rises, at which time Libra sets; the greatest when Libra rises, at which time Aries sets. From the rising of Aries, to the rising of Libra (which is twelve sidereal hours) the angle increases; and from the rising of Libra to the rising of Aries, it decreases in the same proportion; hence it appears that the ecliptic rises fastest about Aries, and slowest about Libra.

On the parallel of London, as much of the ecliptic rises about Pisces and Aries in two hours, as the moon goes through in six days; therefore, whilst the moon is in these signs, she differs but two hours in rising for six days together; that is, about twenty minutes later every day or night than on the preceding, at a mean rate. But in 14 days afterwards, the moon comes to Virgo and Libra, which are the opposite signs to Pisces and Aries; and then she differs almost four times as much in rising; namely, one hour and about 15′ later every day or night than the preceding, whilst she is in these signs. As the signs Taurus, Gemini, Cancer, Leo, Virgo, and Libra, rise successively, the angle of the ecliptic with the horizon increases gradually; and decreases in the same proportion as they set; and for that reason, the moon differs gradually more in the time of her rising every day whilst she is in these signs, and less in her setting: after which, through the other six signs, viz. Scorpio, Sagittary, Capricorn, Aquarius, Pisces, and Aries, the rising difference becomes less every day, until it be at the least of all, namely, in Pisces and Aries.

The moon goes round the ecliptic in about 27 days and 8 hours; but not from change to change in less than about 29½ days: so that she is in Pisces and Aries at least once in every lunation, and in some lunations twice.

If the earth had no annual motion, the sun would never appear to shift his place in the ecliptic; and then every new moon would fall in the same sign and degree of the ecliptic,

and every full moon in the opposite; for the moon would go precisely round the ecliptic from change to change. So that if the moon was once full in Pisces or Aries, she would always be full when she came round to the same sign and degree again. And as the full moon rises at sun-set, (because when any point of the ecliptic sets, the opposite point rises,) she would constantly rise within two hours of sun-set, on the parallel of London, during the week in which she was full. But in the time that the moon goes round the ecliptic from any conjunction or opposition, the earth goes almost a sign forward; and therefore the sun will seem to go as far forward in that time, namely $27\frac{1}{2}°$; so that the moon must go $27\frac{1}{2}°$ more than round, and as much farther as the sun advances in that interval, which is $2\frac{1}{13}°$, before she can be in conjunction with, or opposite to, the sun again. Hence it is evident, that there can be but one conjunction or opposition of the sun and moon in a year in any particular part of the ecliptic. This may be familiarly exemplified by the hour and minute hands of a watch, which in twelve hours are never in conjunction or opposition in that part of the dial-plate where they were so last before.

As the moon can never be full but when she is opposite to the sun, and the sun is never in Virgo and Libra but in our autumnal months, it is plain that the moon is never full in the opposite signs, Pisces and Aries, but in these two months; and therefore we can have only two full moons in the year which rise nearly at the time of sun-set for a week together, as has been mentioned above.

When the moon is in Pisces and Aries, she must rise with nearly the same difference of time in every revolution through her orbit, which is exactly the phenomenon of the harvest moon; but it passes unobserved, because in winter those signs rise at noon, and being then only a quarter of a circle distant from the sun, the moon in them is in her first quarter, and rises about noon, at which time her rising is not noticed. In spring those signs rise with the sun, for the sun is in them, consequently the moon being in them too, is in conjunction with the sun, and therefore her rising is invisible. In summer, those signs rise about midnight; and the sun is three signs, or about 90° before them; therefore the moon in them must be in her third quarter, when she gives little light, and rises late, on which accounts, the phenomenon of her rising for some nights with little difference of time, passes unnoticed. In autumn, however, the case is different; for the signs of Pisces and Aries then rise about sun-set, and therefore the moon being in them, is in opposition to the sun, consequently full, and rises

in great splendour when the sun sets, and seems to prolong the day, for the advantage of the husbandman at the time of harvest.

In northern latitudes, the autumnal full moons are in Pisces and Aries; and the vernal full moons in Virgo and Libra. In southern latitudes, just the reverse, because the seasons are contrary. But Virgo and Libra rise at as small angles with the horizon in southern latitudes, as Pisces and Aries do in the northern; and therefore the harvest moons are just as regular on one side of the equator as on the other.

As those signs, which rise with the least angle, set with the greatest, the vernal full moons differ as much in their times of rising every night, as the autumnal full moons differ in their times of setting; and set with as little difference as the autumnal full moons rise; the one being in all cases the reverse of the other.

Hitherto, to avoid the complication of the subject, the moon's orbit has been supposed to coincide with the ecliptic; but since her orbit makes an angle with the ecliptic, varying from 5° to 5° 18′, one half of it is on one side of the ecliptic, and the other on the other side, and she only coincides with it when at the points of intersection, called her nodes, which coincidence cannot happen less than twice, but sometimes happens thrice, between change and change. For as the moon goes almost a whole sign more than round her orbit from change to change, if she passes through either node at or a little before the time of change, she will pass by the other about fourteen days afterwards, and come round to the former node before the next change. When the moon is northward of the ecliptic, she rises sooner and sets later than if she moved in the ecliptic: and when she is southward of the ecliptic, she rises later and sets sooner. This difference is variable, even in the same signs, because the nodes shift backwards about 19⅓° in the ecliptic every year; and so go round it contrary to the order of the signs in 18 years 228 days.

When the ascending node is in Aries, the southern half of the moon's orbit makes an angle of 5⅓° less with the horizon than the ecliptic does, when Aries rises in northern latitudes: for which reason the moon rises with *less* difference of time when she is in Pisces and Aries, than if she moved in the ecliptic, and will differ only 1 hour and 40′ for the whole of seven days. But in 9 years 114 days afterwards, the descending node comes to Aries, and then the moon's orbit makes an angle of 5⅓° greater with the horizon when Aries rises, than the ecliptic does at that time; which causes the moon to rise with *greater* difference of time in Pisces and Aries than if she moved in the

ecliptic; this difference, in the course of a week, will amount to full 3½ hours. Hence, though we observe the phenomenon of the harvest moon every year, yet it is not every year equally remarkable, but alternately for a period of nearly nine years and a half, it is greatest and least; from 1813 to 1815 is the remainder of a period during which the harvest moon varies most in the time of rising; from 1816 to 1825 includes a period during which the difference is the least.

At the polar circles, when the sun touches the summer tropic, he continues 24 hours above the horizon; and 24 hours below it when he touches the winter tropic. For the same reason, the full moon neither rises in summer, nor sets in winter, considering her as moving in the ecliptic. For the winter full moon being as high in the ecliptic as the summer sun, must therefore continue as long above the horizon; and the summer full moon being as low in the ecliptic as the winter sun, can no more rise than he does. But these are the only two full moons which happen about the tropics; for all the others rise and set. In summer, the full moons are low, and their stay is short above the horizon, when the nights are short, and we have the least occasion for moonlight: in winter the full moons rise high, and stay long above the horizon, when the nights are long, and we want the greatest quantity of moonlight.

At the poles, one half of the ecliptic never sets, and the other half never rises: and therefore, as the sun is always half a year in describing one half of the ecliptic, it is natural to imagine that the sun continues half a year together above the horizon of each pole in its turn, and as long below it; rising to one pole when he sets to the other. This would be exactly the case if there were no refraction; but by the atmosphere's refracting the sun's rays, he becomes visible some days sooner, and continues some days longer in sight, than he would otherwise do: so that he appears above the horizon of either pole before he has got below the horizon of the other. And, as he never goes more than 23½° below the horizon of the poles, they have very little dark night; it being twilight there, as well as at other places, till the sun is 18° below the horizon. The full moon being always opposite to the sun, can never be seen while the sun is above the horizon, except when she is in the northern half of her orbit; for whenever any point of the ecliptic rises, the opposite point sets. Therefore, as the sun is above the horizon of the north pole, from the 20th of March till the 23d of September, it is plain that the moon, when full, being opposite to the sun, must be below the horizon that half of the year. But when the sun is in the southern half of the ecliptic, he never rises to the north

pole; during which half of the year, every full moon happens in some part of the northern half of the ecliptic which never sets. Consequently, as the polar inhabitants never see the full moon in summer, they have her always in the winter, before, at, and after the full, shining for fourteen of our days and nights. Thus the poles are supplied, during one half the winter, with constant moonlight in the sun's absence; and only lose sight of the moon from her third to her first quarter, while she gives but little light, and would be of the least benefit.

The Horizontal Moon.

When the moon is near the horizon, she appears of a shape somewhat elliptical, and larger than when she is in the zenith, or on the meridian. This phenomenon is called the *horizontal moon.*

The longest axis of the elliptical disc of the horizontal moon is parallel with the horizon, but the circular shape is gradually attained, as the moon rises higher. To account for these appearances has greatly exercised the ingenuity of several philosophers, though no solution of the problem has yet been offered, which has received general assent. As the moon when in the horizon is further from us by the semi-diameter of the earth than when in the zenith, the real angle it subtends must at that time be least; but the difference is so small, amounting only to half a minute of a degree, that it would scarcely be noticed by the sharpest eye. Gassendus thought, as the moon was less bright in the horizon than in the meridian, we looked at it, in the former situation, with a greater pupil of the eye, and therefore it appeared larger. An explication of this kind has been lately offered, and experiments are given which appear to shew that a difference of aperture will make a difference in the magnitude of the image of a lens; but more careful experiments shew this conclusion, so opposite to the principles of optics, to be erroneous, and therefore that the variations in the aperture of the pupil of the eye do not occasion variations in the magnitude of the image on the retina. Some have supposed that the image of the horizontal moon on the retina, is not actually larger than at other times, but that we observe such an extent of intermediate objects in that situation, as to give it a greater apparent distance than at other times, and consequently we consider it to be larger, although it subtends only the same angle; the dimness with which it appears, from the fewness of the rays which reach us, contributing at the same time to the deception. The circumstance of faintness does not, however,

seem essential to the phenomenon, otherwise, the moon on the meridian would appear as large as when at the horizon, or nearly so, while it happens to be obscured by clouds; and it may also be remarked, that the lower part of a rainbow appears broader than the upper part, at the same time that it often appears brighter, and the breadth of the moon and of the rainbow in this case are doubtless collateral phenomena. It is evident to the slightest consideration, that the rays of light from the moon, pass through the greatest tract of air, when the moon is in the horizon, and through the least when that luminary is in the zenith; and at all intermediate distances, the quantity of air passed through is of an intermediate extent, and proportionate to the elevation. This is shewn by fig. 6, pl. IV, where AB represents an arc of the top of the atmosphere, and CD an arc of the surface of the earth. When the moon is at H, she is seen by a spectator at E, through the tract *f g* E, which is about twice as long as the tract traversed when she has arrived at the altitude I, and three times the extent of that passed through when she is in the zenith K. May we not then suppose, that the difference in the refraction, produced by the difference in the length of the tract of air passed through by the rays from the moon, is the chief cause of the apparent enlargement of the lunar disc, particularly as we find by experiment, that an object appears larger in proportion as it is viewed at a greater depth in water, and that though a thin piece of flat glass has no perceptible magnifying power, yet a thick piece certainly has, and ought to have, according to the principles of optics. The variations of the density of the vapours through which the rays pass, account for the variations of the horizontal moon, which at equal altitudes sometimes appear larger than at other times. With respect to the elliptical figure of the moon, in the situation mentioned, it must be observed, that the rays from the extremities of its horizontal diameter, strike the convex surface of the atmosphere, and come to the eye with an equal angle, but this is not the case with the rays in the direction of the vertical diameter, and therefore a distortion takes place. A watch-glass fastened upon the surface of a piece of plain thin glass, and the enclosed space filled with water, will illustrate this account of the horizontal moon; for if a small circle be made on a slip of paper, and the circle be held upright nearly on a level with the upper surface, while it is viewed through the under surface of the plain glass, and at the same time through at least half the diameter of the water, the circle will appear elliptical, enlarged in its horizontal and lessened in its vertical diameter; but the distortion will diminish in proportion as it is placed and viewed in a zenith direction.

The sun and stars also appear larger in the horizon, and any two stars appear further apart, than at a greater elevation. The causes of these appearances must be considered the same as that producing the horizontal moon, whether the above explication of this appearance be accurate or not.

Aberration of light.

The fixed stars, and other heavenly bodies, are not seen in their real directions. This circumstance is independent of the refractive power of our atmosphere, and is always present, whether we observe them in the zenith, or any other situation; it is a deviation which arises from the progressive motion of light, and the annual motion of the earth; for the light by which a star is seen, at the time it sets out from the star, is not directed to the spectator, but to a point beyond him, at which, or into the same line with which, his eye will arrive, by the progression of the earth, in exactly the same time that the light requires to reach the earth. This phenomenon is called the *aberration of light*, or *aberration of the fixed stars*.

The aberration of the fixed stars was discovered by Dr. Bradley, in his attempts to ascertain their annual parallax, and he explained it in the following manner: He imagined CA, fig. 7, pl. IV. to be a ray of light falling perpendicularly upon the line BD; that, if the eye is at rest at A, the object must appear in the direction AC, whether light be propagated in time or in an instant. But if the eye is moving from B towards A, and light is propagated in time, with a velocity that is to the velocity of the eye, as CA to BA; then light moving from C to A, whilst the eye moves from B to A, that particle of it by which the object will be discerned when the eye comes to it, is at C when the eye is at B. Joining the points BC, he supposed the line CB to be a tube, inclined to the line BD in the angle DBC, of such diameter as to admit but one particle of light. Then it was easy to conceive, that the particle of light at C, by which the object must be seen, when the eye, as it moves along, arrives at A, would pass through the tube BC, if it is inclined to BD in the angle DBC, and accompanies the eye in its motion from B to A; and that it could not come to the eye placed behind such a tube, if it had any other inclination to the line BD. If, instead of supposing CB so small a tube, we imagine it to be the axis of a larger, then, for the same reason, the particle of light at C would not pass through the axis, unless it is inclined to BD in the angle CBD. In like manner, if the eye moved the contrary way, from D towards A, with the same velocity, then the tube must be inclined in the angle BDC.

Although, therefore, the true or real place of an object is perpendicular to the line in which the eye is moving, yet the visible place will not be so; since that no doubt must be in the direction of the tube; but the difference between the true and apparent place will be greater or less, according to the different proportion between the velocity of light and that of the eye; so that if we could suppose that light was propagated in an instant, then there would be no difference between the real and visible place of an object, although the eye was in motion; for in that case, AC being infinite with respect to AB, the angle ACB, the difference between the true and visible place, vanishes. But if light be propagated in time, it is evident from the foregoing considerations, that there will be always a difference between the real and visible place of an object, unless the eye is moving either directly from or to the object. And in all cases, the sine of the difference between the real and visible place of the object, will be to the sine of the visible inclination of the object to the line in which the eye is moving, as the velocity of the eye is to the velocity of light.

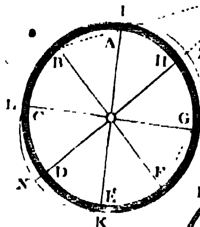
Dr. Bradley then shews, that if the earth revolve round the sun annually, and the velocity of the light be to the velocity of the earth's motion in its orbit, as 1000 to 1, that a star really placed in the very pole of the ecliptic, would, to an eye carried along with the earth, seem to change its place continually; and neglecting the small difference arising from the earth's diurnal revolution on its axis, would seem to describe a circle round that pole, every way distant from it 3½′; so that its longitude would be varied through all the points of the ecliptic every year, but its latitude would always remain the same. Its right ascension would also change, and its declination, according to the different situation of the sun with respect to the equinoctial points, and its apparent distance from the north pole of the equator, would be 7′ less at the autumnal than the vernal equinox.

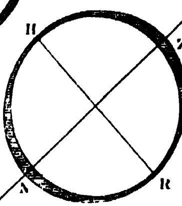
The greatest alteration of the place of a star in the pole of the ecliptic, or which in effect amounts to the same thing, the proportion between the velocity of light and the earth's motion in its orbit being known, it will not be difficult, he observes, to find what would be the difference, upon this account, between the true and apparent place of any other star at any time, and on the contrary, the difference between the true and apparent place being given, the proportion between the velocity of light, and the earth's motion in its orbit, may be found.—Therefore, since the apparent declination of the star γ Draconis, on account of the successive propagation of light, would be to the diameter of the little circle which a star would

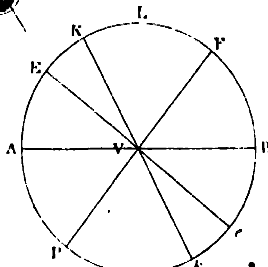
seem to describe about the pole of the ecliptic, as 39″ to 40′.4″; the half of this is the angle ACB. This, therefore, being 20.2″, AC will be to AB, that is, the velocity of light will be to the velocity of the eye, (or the velocity of the earth in its annual motion,) as 10,210 to 1; from which it follows, that light moves as far as from the sun to the earth in 8′ 12″. By the near agreement of multiplied observations, Dr. Bradley proved this statement to be very near the truth.

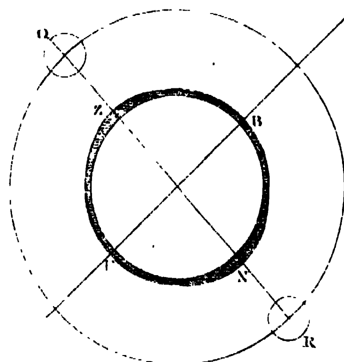
The aberration of the sun and planets is inconsiderable, because while the light is coming from them, the earth has moved but a little way; yet for accurate calculations, it is always taken into account; the sun's aberration is about 20″, that being the space passed over by the earth while his light is coming to us.

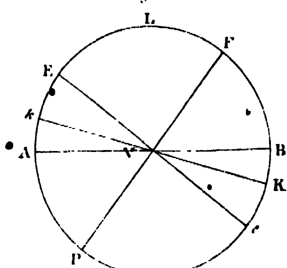
Dr. Bradley's explanation of the aberration of the fixed stars, was no sooner proposed than acceded to by all philosophers, and has never since been questioned. The phenomenon is a strong proof of the annual motion of the earth round the sun, and as the discovery of it so justly gives celebrity to this astronomer's name, the incident which enabled him to explain it so well, and which is given by Dr. Thompson, in his History of the Royal Society, deserves our notice. It shews how much we may improve by habits of observation, and that the most common occurrences may frequently be made subservient to the illustration of the most abstruse points of philosophy. When Dr. Bradley had discovered what is now called the aberration of the fixed stars, and had even completed a whole year's observations, he perplexed himself continually without success to find out the cause of the phenomenon. At last, a satisfactory explanation of it at once occurred to him, when he was not in search of it. He accompanied a pleasure-party in a sail upon the river Thames. The boat in which they were, was provided with a mast, that had a vane at the top of it. It blew a moderate wind, and the party sailed up and down the river for a considerable time. Dr. Bradley remarked, that every time the boat put about, the vane at the top of the boat's mast shifted a little, as if there had been a slight change in the direction of the wind. He observed this three or four times without speaking; at last he mentioned it to the sailors, and expressed his surprise that the wind should shift so regularly every time they put about. The sailors told him the wind had not shifted, but that the apparent change was owing to the change in the direction of the boat, and assured him that the same thing invariably happened in all cases. This accidental observation led him justly to conclude, that the aberration of the stars was owing to the combined motion of light and the earth.

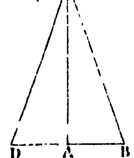

Fig 1
M
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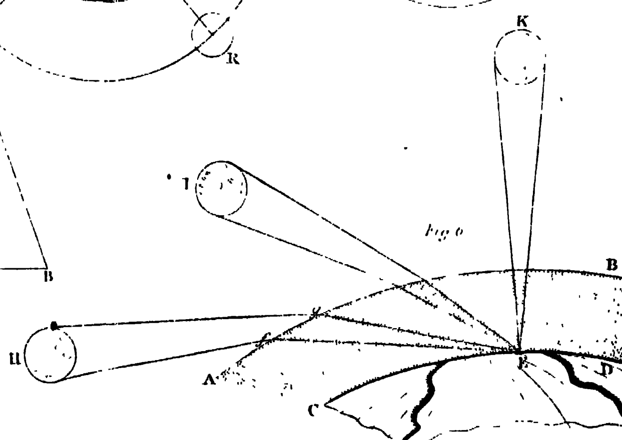

Fig 2.
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Fig 3
S
Q
Z
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N
R


Fig 5
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F
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k
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V
B
K
e
P


Fig 7
C
D
A
B


K
I
Fig 6
B
H
A
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D
C

Nutation of the Earth's Axis.

The discovery of the aberration of the fixed stars, was followed up by Dr. Bradley with an almost incessant assiduity of observation. All his subsequent investigations afforded confirmations of what he had advanced on the subject; and his perseverance was further rewarded, [illegible] own opinion, no doubt, and certainly in that of [illegible] losophers, by another brilliant discovery, which [illegible] *nutation of the earth's axis.* This is a result and a pr[illegible] of the spheroidal figure of the earth. The moon, exerting a greater power of attraction on the equatorial regions of the earth, than on the polar regions, because the mass of matter at the equator is greater than at the poles, causes a libratory motion of the earth's axis, the inclination of which to the ecliptic is, though in a very small degree, continually varying backwards and forwards, so that its extremity describes a small ellipse, the greater diameter of which is about 19.1″ and the less 14.2″. This ellipse is described in the same time as a cycle of the moon, or about 18 years and 7 months.

Precession of the Equinoxes.

When we examine a celestial globe, we find that all the symbols of the constellations are 30 degrees out of what we should consider their true place, or from the constellations themselves. This apparent irregularity has attained its present amount, by the very slow accumulation of 50″ annually. The reason of it is, that the sun does not cut the equator at the same point every year. If, on a certain day, he cuts the equator in a particular point, he will on the same day of the following year cut it in a point 50.25″ westward of the former, and thereby comes to the equinox 20′. 23″ of time before he has completed his circuit of the heavens, or gone from fixed star to fixed star. This phenomenon is called the *precession of the equinoxes.* It makes the tropical year, or true year of the seasons, shorter than the revolution of the sun, or sidereal year, because it is a deviation contrary to the order of the signs. But the intersections of the equator and the ecliptic are still called the beginning of ♈, and the beginning of ♎, though the constellations (being always at the same place) are actually at the distance above stated, from those intersections. The precession of the equinoxes, like the nutation of the earth's axis, is produced by the protuberance of the equator; for when the sun is on either side of the equator, his return to it is has-

tened by his attraction for the greater quantity of matter in that direction. Receding at the rate of 50.25″ westward annually, the equinoxes make an entire revolution in 25,791 years, when the variation commences another period. In consequence of it, those stars which in the infancy of astronomy were in Aries, are now got into Taurus; those of Taurus into Gemini, &c. Hence, likewise, it is, that the stars which rose at any particular season, in the times of the ancients, by no means answer at this time to the description then given of them.

In consequence of the precession, or retrograde motion of the equinoctial points in the heavens, the earth's axis does not preserve an undeviating parallelism, but, with a conical motion describes a small circle, the diameter of which is equal to twice its inclination to the ecliptic, or 47°. This motion may be explained by a diagram: let NZSVL, (fig. 1, pl. V,) be the earth; SONA its axis, produced to the starry heavens, and terminating in A, the present north pole of the heavens, which is vertical to N, the north pole of the earth. Let EOQ be the equator, T♋Z the tropic of Cancer, and VT♑ the tropic of Capricorn; VOZ the ecliptic, and BO its axis, which must be considered immoveable, because the ecliptic always passes over the same stars. But as the equinoctial points recede in the ecliptic, the earth's axis, SON, is in motion upon the earth's centre O, in such a manner as to describe the double cone NO *n* and SO *s*, round the axis of the ecliptic BO, in the time that the equinoctial points move round the ecliptic, that is, in 25,791 years; and in that length of time, the north pole of the earth's axis produced, describes the circle ABCDA in the starry heavens, round the pole of the ecliptic, which keeps immoveable in the centre of that circle. The earth's axis being nearly 23½° inclined to the axis of the ecliptic, the circle ABCDA, described by the north pole of the earth's axis produced to A, will therefore be almost 47° in diameter, or double the inclination of the earth's axis. In consequence of this, the point A, which is at present the north pole of the heavens, and near to a star of the second magnitude, in the end of the Little Bear's tail, must be deserted by the earth's axis; which, moving back one degree in every 71⅔ years nearly, will be directed towards the star or point B in 6447¾ years hence; and in double that time, or 12,895½ years, it will be directed towards the star or point C; which will then be the north pole of the heavens, although it is at present 8½° south of the zenith of London L. The present position of the equator, EOQ will then be changed into *e* O *q;* the tropic of Cancer, T♋, into V *t*♋; and the tropic of Capricorn, VT♑, into *t*♑R; and the sun, in the same part of the heavens where he is now over the

earthly tropic of Capricorn, and makes the shortest days and longest nights in the northern hemisphere, will then be over the earthly tropic of Cancer, and make the days longest and nights shortest. So that it will require 12,895½ years yet more, or 25,791 years from that time, to bring the north pole N quite round, so as to be directed towards that point of the heavens which is vertical to it at present. And then, but not before, the same stars which at present describe the equator, tropics, polar circles, &c. by the earth's diurnal motion, will describe them over again.

Of Eclipses.

The words transit, occultation, and eclipse, are all employed to designate the same general phenomenon, of one heavenly body being lost sight of, either wholly or in part, by the interposition of another; but they are not used indiscriminately. The word *transit* denotes the passage of the inferior planets, Venus and Mercury, over the sun's disc; *occultation*, the disappearance of the stars or planets by the interposition of the moon; and *eclipse*, 1st, to the obscuration of the moon, when this luminary falls into the earth's shadow, called an *eclipse of the moon;* 2nd, to the obscuration of the sun, when the earth falls into the moon's shadow, called an *eclipse of the sun;* and 3rd, to the obscuration of the satellites of any of the planets, by their coming within the shadows of their respective primaries. One of the two first of these three phenomena is always meant, when the word eclipse is used alone.

Eclipses, like comets, were formerly the objects of popular dread, but the age of these vain terrors is now gone by, because it has become a part of popular belief, that they happen according to the common course of nature, which belief is enforced by the notoriety of the fact, that they may be predicted with precision, like the alternations of day and night.

Eclipses of the Moon.

As the earth, like all the rest of the celestial bodies, is globular, the sun can only enlighten one half of it at once; and the hemisphere turned from the sun, will cause a shadow in the regions of space, on account of the light intercepted by its opacity. If the sun and earth were of the same size, this shadow would be almost cylindrical, and of infinite extent; it would not be perfectly cylindrical, because the rays proceed from the sun divergently; but as the earth is very considerably

less than the sun, the shadow is proportionately conical, and though sufficiently long to reach and envelop the moon, it does not reach to the planet Mars. In plate V, fig. 2, S is the sun, E the earth, and M the moon. The dark conical shadow terminates at *f*, just where rays from the upper and lower limbs of the sun, after passing the contour of the earth, meet in a point: on the sides of this conical shadow, there is a diverging shadow *a b c d*, the density of which decreases in proportion as it recedes from the sides of the former conical shadow; this is called the *penumbra*.

When the moon passes entirely through the earth's shadow, the eclipse is *total;* but when only a part of it passes through the shadow, the eclipse is *partial*.

The quantity of the moon's disc which is eclipsed, is expressed by twelve parts, called *digits;* that is, the disc is supposed to be divided by twelve parallel lines; then if half the disc is eclipsed, the quantity of the eclipse is said to be six digits, and so of other proportions.

When the diameter of the shadow through which the moon must pass, is greater than the diameter of the moon, the quantity of the eclipse is said to be more than twelve digits; thus, if the diameter of the moon is to that of the shadow as four to five, then the eclipse is said to be 15 digits.

The general phenomena of lunar eclipses may be classed as follows:—1. All lunar eclipses are universal, or visible in all parts of the earth which have the moon above the horizon; and are every where of the same magnitude, with the same beginning and end.—2. In all lunar eclipses, the eastern side is that which first immerges and emerges again; that is, the left side of the moon as we look towards her from the north; for the proper motion of the moon being swifter than that of the earth's shadow, the moon approaches it from the west, overtakes it, and passes through it, with her east side foremost, leaving the shadow behind, or to the westward.—3. Total eclipses, and those of the longest duration, happen in the very nodes of the ecliptic, because the section of the earth's shadow then falling on the moon, is considerably larger than her disc, and the eclipse is more than 12 digits. There may, however, be total eclipses within a small distance of the nodes; but their duration is the less as they are farther from them, till they become only partial ones, and at last the moon escapes the shadow.—4. The moon, even in the middle of a total eclipse, is not invisible, when the sky is clear, but has an appearance resembling tarnished copper; this appearance is attributed to the rays refracted by the earth's atmosphere into the shadow, of which it consequently diminishes the intensity.—5. the moon

becomes sensibly paler and dimmer, before entering into the real shadow; this is owing to the penumbra.

If the moon's orbit were in the same plane as the ecliptic, or plane of the earth's orbit, she would go through the middle of the earth's shadow, and suffer a total eclipse at every full, and would be totally darkened for above an hour and a half. But one-half of the moon's orbit is elevated five degrees above the ecliptic, and the other half as much depressed below it; consequently the moon's orbit intersects the ecliptic only in the two points before mentioned, called the nodes. When either of these points is in a right line with the centre of the sun, at new or full moon, the sun, moon, and earth, are all in a right line; and if the moon be then full, she falls into the earth's shadow. When the moon is more than 12° from either of the nodes at the time of full moon, she is then generally too high or too low in her orbit to go through any part of the earth's shadow, and no eclipse occurs. But when she is less than 12° from either node at the time of opposition or full, she goes through a greater or less portion of this shadow as she is more or less within this limit. Her orbit contains 360°, of which 12°, the limit of lunar eclipses on either side of the nodes, are but small portions, and therefore, as the sun commonly passes the nodes but twice in a year, it is not extraordinary that the eclipses are so few in number.

The eclipses of the moon, as observed above, are visible from all parts of the earth that have the moon above the horizon at the time, and wherever observed, they are of equal extent; but the time at which they are seen, differs with the difference of longitude, in the same manner as the observations of the satellites of Jupiter, mentioned in page 558, and therefore they are of similar use in determining the longitude of places on the earth. The lunar eclipses are very variable in duration, but never exceed two hours.

Eclipses of the Sun.

As the light of the sun, in its passage to the earth, can only be intercepted by the moon, when the moon is in conjunction with the sun, therefore an eclipse of the sun, or the falling of the earth into the moon's shadow, can only occur at new moon. The moon being a body similar to the earth, its shadow and penumbra are like those occasioned by the earth. This is shewn by fig. 3, plate V; but as the moon is less than the earth, it could not, however near, intercept the whole of the sun's light from the earth, therefore, at the distance of 240,000 miles, and casting a conical shadow, a total eclipse affects

but a small part of the earth at once, and even the penumbra is far from being broad enough to cover the whole terrestrial disc.

The quantity of a solar eclipse is estimated by digits, like an eclipse of the moon.

The general circumstances of solar eclipses are the following: 1. None of them are universal; that is, none of them are seen throughout the whole hemisphere which the sun is then above. Commonly the moon's dark shadow covers only a spot on the earth's surface, about 180 miles broad, as indicated by fig. 3, when the sun's distance is greatest, and the moon's least; but her partial shadow, or penumbra, may then cover a circular space of 4900 miles in diameter, within which the sun is more or less eclipsed, as the places are nearer to or further from the centre of the penumbra. In this case, the axis of the shade passes through the centre of the earth, or the new moon happens exactly in the node, and then it is evident that the section of the shadow is circular; but in every other case, the conical shadow is cut obliquely by the surface of the earth, and the section will be elliptical.—2. A solar eclipse does not appear the same in all parts of the earth where it is seen, but when in one place it is total, in another it is only partial. Also, when the moon appears much less than the sun, as is chiefly the case when she is in apogee and he in perigee, the ver tex of the lunar shadow is then too short to reach the earth, and though she be in a central conjunction with the sun, is yet not large enough to cover his whole disc; the portion we see of him resembles a lucid ring or bracelet, an appearance constituting what is called an *annular eclipse*.—3. A solar eclipse does n t happen at the same time in all places where it is seen; but ap pears more early to the western parts than the eastern, as the motion of the moon, and consequently of her shadow, is from west to east.—4. In most solar eclipses, the moon's disc is covered with a faint light, which is attributed to the reflection of the light from the illuminated part of the earth.—5. In total eclipses of the sun, the moon's limb is seen surrounded by a pale circle of light; which some astronomers consider as an indication of a solar atmosphere, because it has been observed to move equally with the sun, and not with the moon.

Solar eclipses do not happen at every new moon, for the same reason that lunar eclipses do not happen at every full moon, that is, because the orbit of the moon is not coincident with the ecliptic, except in the two nodes; but solar eclipses may happen at the distance of 17° from the nodes, which is a range of 5° on either side more than the arc that comprehends the lunar eclipses.

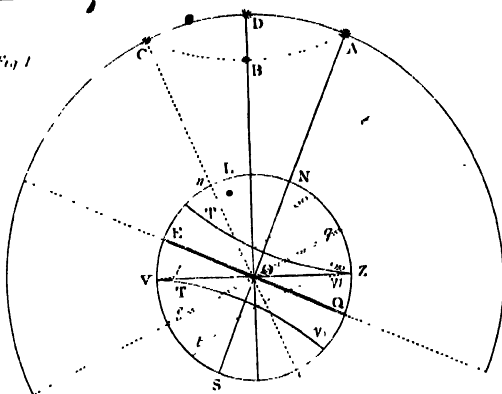
The moon's apparent diameter when largest, exceeds the sun's when least, only 1′ 38″; and in the greatest eclipse of the sun that can happen at any time and place, the total darkness continues no longer than whilst the moon is going 1′ 38″ of a a degree in her orbit, which is about 3′ 13″ of an hour.

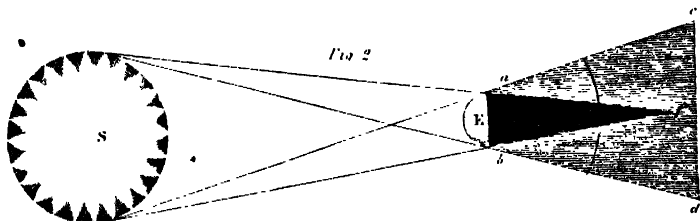
When the penumbra (*a b*, fig. 3) first touches the earth, the general eclipse begins: when the penumbra leaves the earth, the general eclipse ends; from the beginning to the end, the sun appears eclipsed to some part of the earth or other. When the penumbra touches any place, the eclipse begins at that place, and ends when the penumbra leaves it. When the moon changes in the node, the penumbra goes over the centre of the earth's disc as seen from the moon; and consequently, by describing the longest line possible upon the earth, continues the longest upon it, namely, at a mean rate, 5 hours 50′; longer, if the moon be at her greatest distance from the earth, because she then moves slowest; not so long, if she be at her least distance, because of her quicker motion.

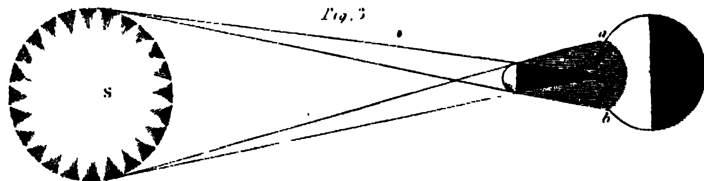
The general phenomena of eclipses will perhaps be made still plainer by reference to the diagram, fig. 4, plate V. Let S be the sun, E the earth, M the moon, and AMP the moon's orbit. Draw the right line W *e* from the western side of the sun at W, touching the western side of the moon at *c*, and the earth at *e:* draw also the right line V *d*, from the eastern side of the sun at V, touching the eastern side of the moon at *d*, and the earth at *e;* the dark space *c e d*, included between those lines, is the moon's shadow, ending in a point at *e*, where it touches the earth; because in this case the moon is supposed to change at M, in the middle, between A, the apogee, or farthest point of her orbit from the earth, and P, the perigee, or nearest point of it. But as any point of the moon's orbit may be directed to the sun, if the point P had been at M, the moon would of course have been nearer the earth, and her dark shadow at *e* would have covered a space upon it about 180 miles broad, and the sun would for a time be totally darkened; but had the point A been at M, the moon would have been farther from the earth, and her shadow would have ended in a point a little above *e*, and therefore the sun would have appeared like a luminous ring all round the moon. Draw the right lines WX *d h*, and VX *c g*, touching the contrary sides of the sun and moon, and ending on the earth at *a* and *b;* draw also the right line SXM, from the centre of the sun's disc, through the moon's centre, to the earth; and suppose the two former lines WX *d h* and VX *c g* to revolve on the line SXM as an axis, and their points *a* and *b* will describe the limits of the penumbra TT on the earth's

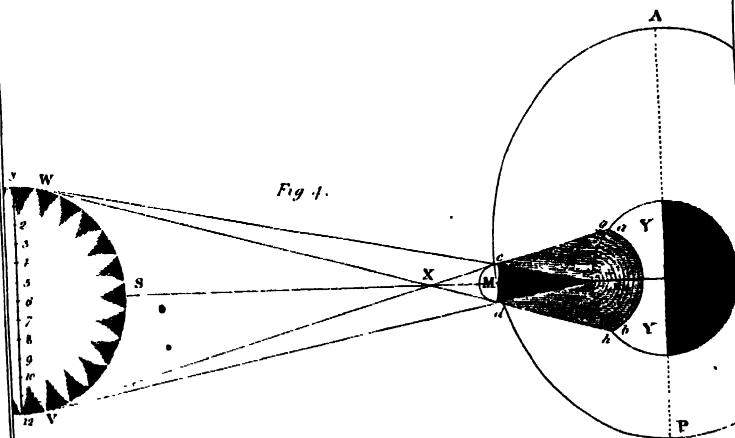
surface, including the large space *a b;* within which penumbra the sun appears more or less eclipsed, as the places are more or less distant from its verge.

Draw the right line *y* 12 across the sun's disc, perpendicular to SXM, the axis of the penumbra; then divide the line *y* 12 into twelve equal parts, as in the figure, for the twelve digits or equal parts of the sun's diameter; and, at equal distances from the centre of the penumbra at *e*, on the earth's surface YY, to its edge *a b*, draw 12 concentric circles, marked with the numeral figures 1 to 12, and remember that the moon's motion in her orbit AMP, is from west to east, as from M to P; then, to an observer on the earth at *b*, the eastern limb of the moon at *d*, seems to touch the western limb of the sun at W, when the moon is at M; and the sun's eclipse begins at *b;* but at the same moment of absolute time, to an observer at *a*, the western edge of the moon at *c* leaves the eastern edge of the sun at V. At the very same instant, to all those who live on the circle marked 1 on the earth, the moon M cuts off or darkens a twelfth part of the sun S, and eclipses him one digit; to those who live on the second circle, the moon cuts off two digits; to those on the circle 3, three digits; and so on to the centre at 12, where the sun is centrally eclipsed. It is evident by the figure, that the sun is totally or centrally eclipsed but to a small part of the earth at any time, because the dark conical shadow at *e* of the moon M, falls but on a small part of the earth, even when it covers the largest space possible; and that the partial eclipse is confined at that time to the space included by the circle *a b*, of which only one half can be projected in the figure, the other half being supposed to be hidden by the convexity of the earth E: and likewise, that no part of the sun is eclipsed to the large space YY of the earth, because the moon is not between the sun and any of that part of the earth; and therefore to all that part the eclipse is invisible. The earth turns eastward on its axis, as from *g* to *h*, which is the same way that the moon's shadow moves; but the moon's motion in her orbit is much swifter than the earth's on its axis; and therefore, although eclipses of the sun are of longer duration on account of the earth's motion on its axis, than they would be if that motion were stopped, yet, in four minutes of time at the most, the moon's swifter motion carries her dark shadow quite over any place that its centre touches at the time of greatest obscuration. The motion of the shadow on the earth's disc, is equal to the moon's motion from the sun, which is about 30½″ of a degree every hour at a mean rate; but so much of the moon's orbit is equal to 30½ degrees of a great circle on the









T. Dixon sculp.

earth; and therefore the moon's shadow goes 30½ degrees, or 1830 geographical miles, on the earth in an hour, or 30½ miles in a minute, which is about four times as swift as the motion of a cannon-ball.

Description of a total Eclipse of the Sun.

As total eclipses of the sun are very rare phenomena, we shall here give the excellent description of one sent by Dr. Stukely, to his friend Dr. Edmund H-" . Its general interest is much increased by the cir .tance that the author, from being unprovided with instruments, describes the spectacle rather as a general, though intelligent, observer of nature, than an astronomer.

"According to my promise, I send you what I observed of the solar eclipse, though I fear it will not be of any great use to you. I was not prepared with any ·i truments for measuring time or the like, and proposed t .yself only to watch all the appearances that nature would present to the naked eye upon so remarkable an occasion, and which generally are overlooked, or but grossly regarded. I chose for my station a place called Haradon Hill, two miles eastward from Amsbury, and full east from the opening of Stonehenge avenue, to which it is as the point of view. Before me lay the vast plain where that celebrated work stands, and I knew that the eclipse would appear directly over it; besides, I. had the advantage of a very extensive prospect every way, this being the highest hill hereabouts, and nearest the middle of the shadow; full west of me, and beyond Stonehenge, is a pretty copped hill, like the top of a cone, lifting itself above the horizon; this is Clay-hill, near Warminster, 20 miles distant, and near the central line of darkness, which must come from thence, so that I could have notice enough before-hand of its approach. Abraham Sturgis and Stephen Ewens, both of this place, and sensible men, were with me. Though it was very cloudy, yet now and then we had gleams of sunshine, rather more than I could perceive at any other place around us. These two persons looking through smoked glasses, while I was taking some bearings of the country with a circumferentor, both confidently affirmed the eclipse was begun, when by my watch I found it just half an hour after 5; and accordingly, from thence the progress of it was visible, and very often to the naked eye; the thin clouds doing the office of glasses. From the time of the sun's body being half covered, there was a very conspicuous circular iris round the sun with perfect colours. On all sides, we beheld the shepherds hurrying their flocks into fold, the

Scenery of nature, during a solar eclipse, delineated.

darkness coming on; for they expected nothing less than a total eclipse for an hour and a quarter.

"When the sun looked very sharp like a new moon, the sky was pretty clear in that spot; but soon after a thicker cloud covered it, at which time the iris vanished, the copped hill before mentioned grew very dark, together with the horizon on both sides, that is, to the north and south, and looked blue; just as it appears in the east at the declension of day. We had scarce time to tell ten, when Salisbury steeple, six miles off southward, became very black; the copped hill quite lost, and a most gloomy night with full career came upon us. At this instant we lost sight of the sun, whose place among the clouds was hitherto sufficiently distinguishable, but now not the least trace of it to be found, no more than if really absent: then I saw by my watch, though with difficulty, and only by help of some light from the northern quarter, that it was 6 hours 35 minutes. Just before this, the whole compass of the heavens and earth looked of a lurid complexion, properly speaking, for it was black and blue, only on the earth, upon the horizon, the blue prevailed; there was likewise in the heavens, among the clouds, much green interspersed, so that the whole appearance was really very dreadful, and as symptoms of sickening nature.

"Now I perceived us involved in total darkness and palpable, as I may aptly call it; though it came quick, yet I was so intent, that I could perceive its steps, and feel it as it were drop upon us, and fall on the right shoulder (we looking westward) like a great dark mantle or coverlet of a bed thrown over us, or like the drawing of a curtain on that side; and the horses we held in our hands were very sensible of it, and crowded close to us, startling with great surprise; as much as I could see of the men's faces that stood by me, had a horrible aspect. At this instant I looked around me, not without exclamations of admiration, and could discern colours in the heavens, but the earth had lost its blue, and was wholly black; for some time among the clouds, there were visible streaks of rays tending to the place of the sun as their centre; but immediately after the whole appearance of earth and sky was entirely black: of all things I ever saw in my life, or can by imagination fancy, it was a sight the most tremendous.

"Toward the north-west, whence the eclipse came, I could not in the least find any distinction in the horizon between heaven and earth, for a good breadth of about sixty degrees or more; nor the town of Amsbury underneath us, nor scarce the ground we trod on. I turned myself round several times during this total darkness, and remarked at a good distance from the

west on both sides, that is to the north and south, the horizon very perfect; the earth being black, the lower part of the heavens light; for the darkness above hung over us like a canopy, almost reaching the horizon in those parts, or as if made with skirts of a lighter colour; so that the upper edges of all the hills were as a black line, and I knew them very distinctly by their shape or profile; and northward I saw perfectly, that the interval of light and darkness in the horizon was between Martinsal-hill and St. Ann's hill; but southward it was more indefinite. I do not mean that the verge of the shadow passed between those hills, which were but 12 miles distant from us; but, so far I could distinguish the horizon, beyond it not at all: the reason of it is this: the elevation of ground I was upon, gave me an opportunity of seeing the light of the heavens beyond the shadow; nevertheless, this verge of light looked of a dead, yellowish, and greenish colour; it was broader to the north than south, but the southern was of a tawny colour. At this time behind us, or eastward toward London, it was dark too, where otherwise I could see the hills beyond Andover; for the foremost end of the shadow was past thither; so that the whole horizon was now divided into four parts of unequal bulk, and degrees of light and dark: the part to the north-west broadest and blackest; to the south-west lightest and longest. All the change I could perceive during the totality, was that the horizon by degrees drew into two parts, light and dark; the northern hemisphere growing still longer, lighter, and broader; and the two opposite dark parts uniting into one, and swallowing up the southern enlightened part.

"As at the beginning, the shade came feelingly upon our right shoulders, so now the light from the north, where it opened as it were; though I could discern no defined light or shade upon the earth that way, which I earnestly watched for, yet it was manifestly by degrees, and with oscillations, going back a little, and quickly advancing further, till at length, upon the first lucid point appearing in the heavens, where the sun was, I could distinguish pretty plainly a rim of light running alongside of us a good while together, or sweeping by at our elbows from west to east; just then having good reason to suppose the totality ended with us, I looked on my watch, and found it to be full three minutes and a half more. Now the hill-tops changed their black into blue again, and I could distinguish an horizon where the centre of darkness was before; the men cried out, they saw the copped hill again, which they had eagerly looked for; but still it continued dark to the south-east, yet I cannot say that ever the horizon that

way was undistinguishable; immediately we heard the larks chirping, and singing very briskly, for joy of the restored luminary, after all things had been hushed into a most profound and universal silence. The heavens and earth now appeared exactly like morning before sun-rise, of a grayish cast, but rather more blue interspersed; and the earth, so far as the verge of the hill reached, was of a dark green or russet colour.

"As soon as the sun emerged, the clouds grew thicker, and the light was very little amended for a minute or more, like a cloudy morning slowly advancing. After about the middle of the totality, and so after the emersion of the sun, we saw Venus very plainly, but no other star. Salisbury steeple now appeared. The clouds never removed, so that we could take no account of it afterwards, but in the evening it lightened very much. I hasted home to write this letter; and the impression was so vivid upon my mind, that I am sure, I could for some days after have wrote the same account of it, and very precisely. After supper I made a drawing of it from my imagination, upon the same paper I had taken a prospect of the country before.

"I must confess to you, that I was (I believe) the only person in England that regretted not the cloudiness of the day, which added so much to the solemnity of the sight, and which incomparably exceeded, in my apprehension, that of 1715, which I saw very perfectly from the top of Boston steeple, in Lincolnshire, where the air was very clear; but the night of this was more complete and dreadful: there, indeed, I saw both sides of the shadow come from a great distance, and pass beyond us to a great distance; but this eclipse had much more of variety and majestic terror; so that I cannot but felicitate myself upon the opportunity of seeing these two rare accidents of nature, in so different a manner: yet I should willingly have lost this pleasure for your more valuable advantage of perfecting the noble theory of the celestial bodies, which last time you gave the world so nice a calculation of; and wish the sky had now as much favoured us, for an addition to your honour and great skill, which I doubt not to be as exact in this as before."

Division of Time.

Time is distinguished into *absolute* and *relative*.

Absolute time, is time considered in itself, and without any relation to bodies or their motions.

Relative time, is the time measured by means of motion, as by the motion of the heavenly bodies, timekeepers, &c. Motion affords us the only means we possess, of rendering the flow of absolute time perceptible.

Astronomical time, is that measured by the motion of the heavenly bodies.

Civil time, is astronomical time accommodated to civil uses, and distinguished into days, months, years, &c.

Of the Day, and smaller portions of Time.

In common language, the day is the interval of time which elapses from the rising to the setting of the sun; this is called the *artificial day,* the night is the interval that the sun continues below the horizon.

The time which elapses during an entire revolution of the sun, from a meridian to the same meridian again, is called an *astronomical* or *natural day.* It commences at 12 o'clock at noon, when the sun's centre is on the meridian, and terminates at the next noon, when the sun's centre is again on the meridian. It is divided into 24 hours, reckoning in a numerical succession from 1 to 24: the first 12 are sometimes distinguished by the mark P.M. signifying *post meridiem,* or afternoon; and the latter twelve are marked A. M. signifying *ante meridiem,* or before noon. But astronomers generally reckon through the 24 hours, from noon to noon; and those hours which are by the civil or common way of reckoning called morning hours, they reckon in succession from 12 or midnight, to 24 hours. Thus 10 o'clock in the morning of June the 11th, they would call the 22d hour of June the 11th.

The length both of the astronomical and the civil day is constantly changing. This variation arises from two causes: 1. The unequal motion of the earth in its orbit. 2. The obliquity of that orbit to the plane of the equator. The mean and apparent solar days are never equal, except when the sun's daily motion in right ascension is 59′ 8″. This is the case about April 16, June 16, September 1, and December 25: on these days the difference vanishes, or nearly so. It is at its greatest about November 1, when it is 16′ 16″.

An astronomical day is somewhat greater than a *sidereal year,* which is the time employed by the earth in revolving on its axis, and is at all times of the year immutably the same. It will easily be understood, that at every complete rotation of the earth, the same fixed stars will be on the meridian; but that this cannot be the case with the sun, because, during the earth's rotation, the sun* has advanced eastward and left the star, and therefore the earth has to make somewhat more than one turn before the sun comes a second time to the same meridian. If the mean astronomical or civil day be taken equal to 24 hours, the duration of the sidereal day will be 23h. 56′ 4.1″. Hence a star which was on the meridian with the sun, will be on the meridian 3′ 56″ before the next noon; 3′ 56″ being the difference between a solar and sidereal day.

The civil day, or astronomical day accommodated to civil purposes, begins with different nations at different times: The Egyptians began their day at midnight; the same method prevails in Great Britain, France, Spain, and most parts of Europe. The Babylonians began their day at sun-rising, reckoning the hour immediately before its rising again, the 24th hour of the day, whence the hours reckoned in this way are called the Babylonic. In several parts of Germany and Italy, they begin their day at sun-setting, and reckon on till it sets next day, calling that the 24th hour: these are generally termed Italian hours. The Jews also began their day at sun-setting, but then, like us, they divided it into parts of 12 hours each. The Romans also reckoned their hours in this manner, and the Turks do the same at this day.

An hour may be considered either as an equal or unequal portion of time. Equal hours, or those in common use, are the twenty-fourth part of a day and night precisely. They are likewise called equinoctial hours, because they are measured on the equinoctial; and astronomical, because used by astronomers. Unequal hours are those by which the artificial day is

* Nothing is more common, in astronomical treatises, than to speak of the sun's motion, as if that luminary had a real motion in the ecliptic or through the zodiac. This mode of speech is used, because it is easily explained, that the sun's motion, like that of the shore to a person in a ship, is only apparent, the real motion belonging to the earth, which, in different situations of its orbit, necessarily induces the terrestrial spectator to transfer the situation of the sun to a different position in the sphere. It is an accommodation to the ordinary testimony of our senses, that introduces no confusion of ideas; but it shews at the same time, that even in this day, a mode of speech is thought expedient, that in early ages was certainly indispensable, when the sun was commanded to stand still, and virtually obeyed.

divided into 12 parts, and the night into the same number. As it is only at the time of the equinoxes that the artificial day is equal to the night, they will, except at these times, be always either increasing or decreasing.

The hour is divided into 60 equal parts called *minutes;* each minute into 60 equal parts called *seconds;* and each second into 60 equal parts called *thirds.* The Jews, Chaldeans, and Arabians, divided the hour into 1080 equal parts, called *scruples;* which number containing 18 times 60, each minute contains 18 scruples.

Of the Week.

Various divisions of this sort have obtained in different countries, and at different times. The early Greeks divided their month into three portions of ten days each; the Northern Chinese had a week of fifteen days, and the Mexicans one of thirteen; but the most general division of the month was that of the Jews, into periods of 7 days. This period was adopted by the Chaldeans, and most other Oriental nations. It is at this day in use wherever Christianity has been introduced. The French abandoned it for the decade during the season of revolutionary frenzy, but their late Dictator brought it back to its former standard. The Mahometans also use the week of 7 days.

Of the Moon.

The periodical changes of the phases of the moon, it seems very apparent, gave rise to the division of time called a month; but the difficulty of adjusting the lunar month to the annual revolution of the earth, led to the introduction of other divisions of time under the same name.

Months are now divided into *astronomical* and *civil.*

The *astronomical months,* with which chronology is concerned, are measured by the revolutions of the moon, and are either *periodical* or *synodical.*

The *periodical lunar month,* or the exact time in which the moon passes through the zodiac, from any point of her orbit to the same point again, consists of 27 days, 7 hours, 43′ 5″.

The *synodical lunar month,* called a *lunation,* is reckoned from one conjunction of the sun with the moon to another. It is a variable period, being subject to the variation of the sun eastward on the ecliptic; at a mean rate, a lunation consists of 29 days, 12 hours, 44′ 3″. In ancient times, this was the month in general use.

The *solar month* is the time in which the sun passes through one sign of the zodiac; its length is variable, because the motion of the sun is so: at a mean rate, it consists of 30 days, 10 hours, 29′ 5″.

A *civil* or *political month* is a portion of time set out by the custom of particular nations, without any precise regard to the celestial motions. The British and most European nations make twelve months in the year.

Civil lunar months consist alternately of 29 and 30 days Thus two of these months are nearly equal to two astronomical months, and the new moon will be kept to the first day of such civil months for a longer time together. This was the month in common use till the time of Julius Cesar.

The *civil solar month* is the one at present in use. It was introduced by Julius Cesar. It consisted at first alternately of 30 and 31 days, excepting one month of the twelve, which in every fourth year consisted of thirty, and for the other three years of 29 days. This arrangement was altered a little by Augustus, whose name was given to the month previously called Sextilis, and to make it equal to any of the rest, the number of the days it contained was increased from 30 to 31. The day thus added to it, was taken from February, which month, from that time, had only 28 days, except in every fourth year, when it received the intercalary day. The civil months thus determined in the reign of Augustus, have remained in use to the present time, and are common to all Europe; they are the same with what we usually call calendar months.

Of the Year.

The smaller divisions of time, under the same name, differing from each other according to the motion by which they are measured, it will necessarily follow that the large divisions will admit variations, according to the value of their integral parts.

The *solar year*, or *tropical year*, is the time that the sun takes to pass through the twelve signs of the zodiac, or from one equinox to the same again, and constitutes a natural division of time, because the seasons always fall in the same months. Its length is equal to 365 days, 5 hours, 48′ 49″.

The tropical year is divided by astronomers into four parts, determined by the two equinoxes and solstices. The interval between the vernal and autumnal equinoxes is (on account of the eccentricity of the earth's orbit, and its unequal velocity therein) nearly 8 days longer than the interval between the

autumnal and vernal equinoxes. These intervals are at present nearly as follows:—

	D.	h.	m.	D.	h.	m.
From the Spring equinox to the summer solstice......	92	21	45	186	11	20
Summer solstice to the autumnal equinox....	93	13	35			
Autumnal equinox to the winter solstice.....	89	16	47	178	18	29
Winter solstice to the spring equinox	89	1	42			
				7	16	51

The Julian year, so named by Julius Cesar, who established it,* consists of 365 days, 6 hours; but the 6 hours were not reckoned till the expiration of every fourth year, when, amounting just to one day, they were added to the end of February, and the year in which they were thus reckoned was called *bissextile* or *leap year*. The Julian year exceeding the true solar year more than 11 minutes, the excess amounts to a whole day in 131 years; in consequence of which, the vernal equinox, which in the first Julian year fell on the 25th of March, had in the year of our Lord 325, at the time of the council of Nice, gone back to the 21st, and in 1582 to the 11th of March. To correct this growing error, the calendar was again amended, under the auspices of Pope Gregory XIII. by taking 10 entire days out of it. Accordingly, in the year 1582, the day following the 4th of October, instead of being called the 5th was called the 15th; by means of which the real equinox was restored to the 21st of March. A provision was at the same time made, to prevent the recurrence of so important an error again. The intercalary or bissextile day, which had been regularly added to February every fourth year, was ordered to be suppressed at the end of every century not divisible by 4. The last year of the 17th, 18th, and 19th centuries are not leap-years, because 4 will not divide these numbers without a remainder; but the last year of the 20th century, or year 2000, will be a leap-year. This pope's correction of the calendar is so near the truth, that it will not err a day in 3000 years; it is called the *Gregorian*, or the *New Style*, and obtains in almost all Christian nations. It was not used in England before 1752, when it was adopted pursuant to act of parliament, and the third of September was reckoned the fourteenth, the error of the Julian calendar having at that time increased to 11 days.

The lunar year is the space of 12 lunar months, and is either astronomical or civil.

The *lunar astronomical year* consists of twelve lunar synodi-

cal months; and is, therefore, 354 days, 8 hours, 48′, 38″, being 10 days, 21 hours, 11″ shorter than the solar year.

The *lunar civil year* is either common or embolimic. The common lunar year consists of 12 lunar civil months, and contains 354 days. The embolimic lunar year consists of 13 lunar civil months, and contains 384 days.

The ancient Roman year, as first settled by the Romans, contained only 10 months, and in all 304 days.

The Egyptian year, called also the year of Nabonassar, contains only 365 days, divided into 12 months of 30 days each, with five intercalary days added at the end. Thus the Egyptian year loses a whole day of the Julian year every four years, and after the space of 1460 years, it begins with the Julian year, which length of time is called the *Lothic period.*

The ancient Greek year consisted of 12 months, which at first were divided into 30 days each; but afterwards each month contained 29 and 30 days alternately; and this year was computed from the first appearance of the new moon, with the addition of an embolimic month of 30 days, every 3d, 5th, 8th, 11th, 14th, 16th, and 19th year, in order to keep the new and full moons to the same seasons of the year.

Not only the length of the year, but the time of its commencement, has been differently reckoned among different nations. The Chaldeans and Egyptians commenced their year at the autumnal equinox. The Jews reckoned their civil year from the same period, but began their ecclesiastical year in the spring. Some of Grecian states commenced their year at the vernal equinox, others at the autumnal equinox, and some at the summer solstice. The Roman year at one time began in March, but afterwards was made to commence in January. The new year's day of the church of Rome is fixed on the Sunday nearest the full moon of the vernal equinox. In England, the year began in March, till 1752, when the style was altered, and the year was at the same time settled to commence on the first of January. The period between the 1st of January and the 25th of March, was for some time subsequently to the alteration of the style, expressed thus: 1735-6, or $173\frac{5}{6}$, forms of writing which have now become obscure.

Of the Lunar and Solar Cycles and Indiction.

A cycle is a perpetual circulation of a certain fixed and determinate space of time.

The *cycle of the sun* consists of 28 years; at the end of which time, the days of the months return again to the same

days of the week, and the sun is in the same sign and degree of the ecliptic, which he was in at its commencement; at least, this is the case within a degree for 100 years. The leap-years, also, at the expiration of the solar cycle, begin the same course over again with respect to the days of the week on which the days of the months fall.

The *cycle of the moon*, the year of which is called the golden number, is a period of 19 years, at the end of which time, the sun and moon return to the same situation in the heavens, or very nearly so: the conjunctions, oppositions, &c. of these two luminaries being, within about an hour and a half, the same that they were on the same days of the months at the commencement of the period.

The *cycle of indiction*, or Roman indiction, has no reference to any natural period. It consisted of 15 years, and was in use only among the Romans, for some civil purposes which cannot now be completely ascertained.

The year of our Saviour's birth, according to the usual computation, was the ninth year of the solar cycle; the first year of the lunar cycle; and the 312th year after his birth was the first year of the Roman indiction. With this data, the year of any subsequent cycle or indiction may be found.

Of Epochs and Eras.

Any remarkable event or period from which time is reckoned, is called an *epoch;* the years computed from an epoch, or from such event or period, are called an *era*, whatever be their number.

The earliest and most memorable epoch connected with mundane affairs, is that of the creation of the world; but the era referring to it is only continued to the birth of Christ. According to Archbishop Usher, whose chronology is adopted in the current translation of the Bible, it began in the year 4004 before Christ. Playfair places it in 4007. The next epoch was the Deluge, and like the former it was used by the Jews.

The epoch adopted by all Christians is that of the birth of Christ; the common estimation of which, making the present year of the Christian era 1814, is supposed to be 4 years too late. The reason of this uncertainty is, that the Christian era was not used till the sixth century after the birth of Christ, when it was too late to fix its commencement with indisputable accuracy. But as all the nations who use it, begin at the same time, and the year 1814, for example, is with all of them the year 1814, the error introduces no confusion.

The mode of reckoning by *olympiads*, or periods of four years, was used by the Greeks. The first olympiad began 775 years before the birth of Christ.

The Romans reckoned from the building of Rome; the date of that event is, however, not well ascertained, from the want of authentic records in those early times; but the computation adopted by the Romans themselves, places it in the year 753 before Christ.

The Hegira, or Mahometan era, takes date from the flight of Mahomet to Medina, 622 years after the commencement of the Christian era.

To obtain a common standard in the comparison of dates and eras, Joseph Scaliger adopted a very ingenious method: By multiplying into each other, the cycle of the sun, which is 28 years; the cycle of the moon, which is 19 years; and cycle of indiction, which is 15 years, he obtained the number 7980, which is called a *Julian period*. This period is supposed to commence 706 years antecedently to the creation, and till the expiration of it, or till the world is 7274 years old, the first years of each of these cycles will not come together.—The year of the Julian period corresponding with any given year before or since the commencement of the Christian era may easily be found. If the year required be since the Christian era, add to it 4713, the number of years elapsed before the Christian era, and the sum will be the year required. If the year required precede the Christian era, subtract the years before Christ from 4713, and the difference will be the answer.



Abstract of Astronomy

1. The solar system, comprises the sun and all the bodies that revolve round him, viz. the comets, the planets with their respective satellites, and the asteroids.

2. The number of the comets is unknown; that of the planets, so far as yet discovered, is seven, the satellites eighteen; and the asteroids four.

3. The figure of the earth is not that of a perfect globe, but an oblate spheroid, flattened a little at the poles, by its revolution on its axis.

4. The planets Jupiter and Saturn are also observed to be flattened at the poles like the earth, but in a greater degree, evidently because their diurnal revolution is swifter.

5. The orbits of all the planets, asteroids, and comets, are ellipses, having the sun in one of their foci; but the orbits of the two former classes of bodies are nearly circular, while the orbits of the comets are all very eccentric.

6. The orbits of the satellites are also ellipses in one of the foci of which is situated the primary planet round which they move.

7. The periods, distances, and magnitudes of the planets, have all been determined with very considerable exactness; the same circumstances respecting the asteroids, are also evidently determinable, though the results yet laid down, have not, from the recent date of their discovery, been so amply confirmed, as to be fully relied on; but the comets recede to such immense distances, and there is so much uncertainty in identifying them, that their elements are hypothetical.

8. The planets, comets, and asteroids, are preserved in their orbits, by the joint effects of the power of attraction, which acts in a right line from them to the sun, and a projectile or centrifugal force, which would carry them off in a tangent to the curve of revolution.

9. The powers which preserve the satellites in their orbits, are the same as those that act upon the planets and comets, but the centripetal force is exercised by the primary.

10. The body of the sun is supposed to be opaque, and to be surrounded with a double set of clouds, the upper stratum of which forms the luminous globe we behold.

11. The planets revolve round an imaginary line or axis within themselves, and the time in which they perform this rotation, constitutes their *day* and *night*.

12. The time in which a planet revolves round the sun, forms its *year*.

13. The diversity of seasons is occasioned by the inclination of the axis of a planet to the plane of its orbit.

14. The annual and diurnal revolutions of the planets are all performed from west to east.

15. The satellites also revolve from west to east, with the exception of the satellites of the Herschel, which appear to move in a contrary direction.

16. The fixed stars are distinguished from the bodies of the solar system, by the twinkling light they afford, by their having no parallax, and by their having, even through the best telescopes, no sensible magnitude.

17. The naked eye cannot behold above five hundred stars in the whole hemisphere; but the number discovered with the assistance of a telescope exceeds all calculation.

18. Every fixed star is supposed to be a sun, shining by its

own light, and surrounded by planetary worlds like those of the solar system.

19. The tides are an effect of the attraction of the sun and moon upon the ocean. When these luminaries act together, or in the same line, they occasion spring tides; when they counteract each other's attraction, *neap tides* take place.

20. Eclipses of the moon are owing to the shadow of the earth falling upon the moon.

21. Eclipses of the sun occur, when the moon, coming between the earth and sun, throws a shadow on the earth.

22. Motion is the measure of time, and the motions of the heavenly bodies are the basis by which all other motions are measured.

23. The day is a natural division of time, that is, it comprises a portion of time measured out by the completion of certain phenomena, successive according to regular laws.

24. The periodical and synodical lunar months are also natural divisions of time, but no other; the year, and lunar and solar cycles, are of the same character as the lunar months; the cycle of indiction, and the olympiad, are examples of the artificial division of time.

END OF VOLUME FIRST.